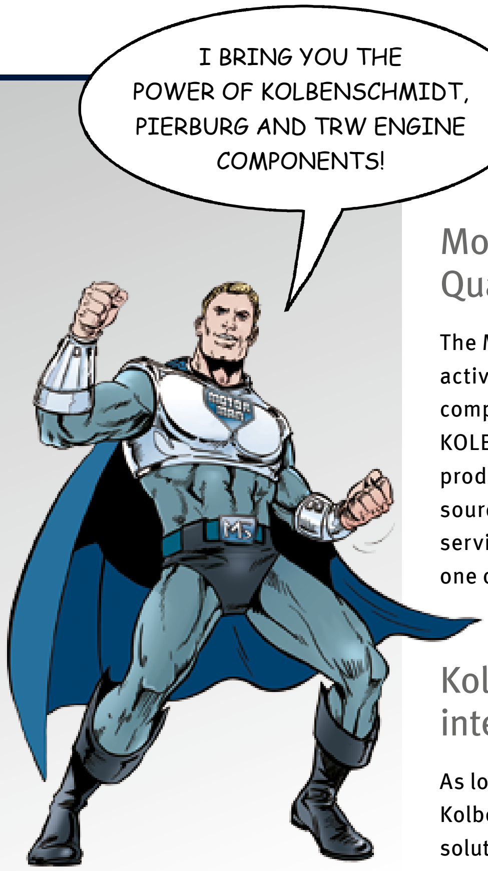
Piston Rings for Combustion Engines

SERVICE
TIPS & INFOS


I BRING YOU THE POWER OF KOLBENSCHMIDT, PIERBURG AND TRW ENGINE COMPONENTS!
MS

Motor Service Group. Quality and Service from a single source.

The Motor Service Group is the sales organisation for the worldwide aftermarket activities of Kolbenschmidt Pierburg. It is one of the leading suppliers of engine components for the independent aftermarket including the premium brands KOLBENSCHMIDT, PIERBURG and TRW Engine Components. Our comprehensive product range allows our customers to procure engine components from a single source. As a problem solver for dealers and garages, Motor Service offers extensive services and the technical expertise that you would expect from the subsidiary of one of the largest automotive suppliers.

Kolbenschmidt Pierburg. Renowned supplier to the international automotive industry.

As long-standing partners to the automotive industry, the companies in the Kolbenschmidt Pierburg Group develop innovative components and system solutions with acknowledged competence in air supply and emission control, for oil and water pumps, for pistons, engine locks and engine bearings. The products comply with the high demands and quality standards of the automotive industry. Low emissions, reduced fuel consumption, reliability, quality and safety – these are the forces that drive innovation at Kolbenschmidt Pierburg.

2nd Edition 01.2010
Article Number 50 003 958-02
ISBN 978-3-86522-492-7

Edited by:
Motor Service Technical Market Support

Layout and production:
Motor Service Marketing
DIE NECKARPRINZEN GmbH, Heilbronn

This document must not be reprinted, duplicated or translated in full or in part without our prior written consent and without reference to the source of the material.

All content including pictures and diagrams is subject to alteration. No liability accepted.

Published by:
© MS Motor Service International GmbH

Liability
All information in this brochure has been carefully researched and compiled. Nevertheless, it is possible that errors have occurred, information has been translated incorrectly, information is missing or the details provided have changed in the intervening time. As a result, we are unable to provide any guarantee nor to accept any legal liability for the accuracy, completeness, currency or quality of the information provided. We hereby waive all liability for any damages, whether direct or indirect in nature and whether tangible or intangible, resulting from the use or misuse of information or from incomplete or incorrect information in this brochure, unless proven to be the result of deliberate intent or negligence on our part.

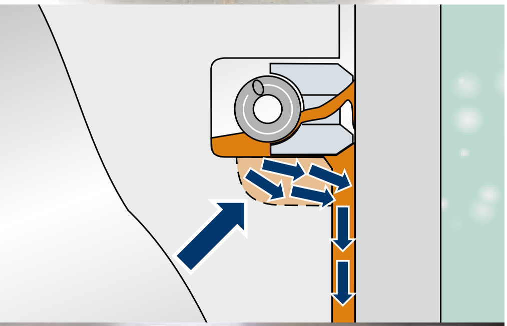
Likewise, we shall not be liable for damage arising because the engine reconditioner or mechanic does not have the necessary technical expertise, the required knowledge of, or experience in repairs.

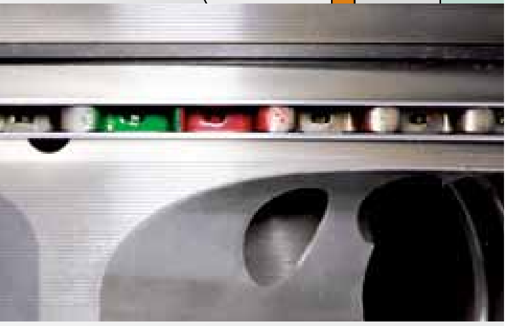
The extent to which the technical methods and repair information described here will apply to future engine generations cannot be predicted and must be verified in individual cases by the engineer servicing an engine or the workshop operator.

Contents

Contents	Page
1 | Basics	5
1.1 | Requirements on piston rings	5
1.2 | The three main functions of piston rings	6
1.3 | Types of piston rings	8
1.4 | Piston ring designations	18
1.5 | Structure and shape of piston rings	19
1.6 | Functions and characteristics	26
2 | Installation and service	39
2.1 | Assessment of used components	39
2.2 | Assessment of used pistons	40
2.3 | Assessment of used cylinder bores	42
2.4 | Assembly of pistons and piston rings	48
2.5 | Initial start and running-in of engines	55
2.6 | Sealing problems and piston ring damage	59
2.7 | Lubrication and oil consumption	69

Preface





The issue

Piston rings have been in use for as long as combustion engines themselves. Despite this, ignorance or inadequate knowledge of piston rings is still frequently evident today. No other component is so critical when power loss and oil consumption are at stake. With no other component in the engine is the divide between expectations and utilised capital greater than when replacing piston rings.

All too often, confidence in piston rings suffers due to the exaggerated demands made on them. Consequently - and even against one's better judgement - halftruths and lies, clichés and false estimations remain in force in repair workshops and among consumers. However, piston rings are most often adversely affected by cheap repairs (for instance by reusing worn-out interacting sliding parts) and by unqualified installation.

This brochure

In this brochure we have taken a user approach to the topic of piston rings. We have deliberately refrained from concentrating too deeply on structural data and have instead focused on the more practical aspects. Wherever we do address design-engineering and development topics, this is simply for better understanding or supplementary to other information.

The content of this brochure deals mainly with piston rings for personal and utility vehicles. Engines that were originally designed for automobile applications, but have been installed e.g. in ships, railroad engines, construction machines and stationary motors, are of course also included in this category. Besides a section with basic technical principles, the practical section "Installation and Service" contains detailed information on fitting and replacing piston rings as well as useful related topics such as lubrication, oil consumption and running in the engine.

Successful repair and maintenance work is not difficult if you are aware of the interrelations inside the engine. We point out what is necessary to assure that repairs are a success, but also show what can happen if certain rules are not observed.

Pictograms and symbols

The following pictograms and symbols are used in this brochure:

⚠

Caution – Draws your attention to dangerous situations with possible personal injuries or damage to vehicle components.

☞

Reference to useful advice, explanations and supplementary information for handling.

1.1

Requirements on piston rings

Piston rings for combustion engines must meet all requirements on dynamic linear sealing. They must not only withstand thermal and chemical influences, but also achieve a series of functions and characteristics which are listed below:

Functions:

- Preventing (sealing) the passage of gas from the combustion chamber into the crank case to avoid loss of gas pressure and, consequently, of engine performance.
- Sealing, i.e. preventing the passage of lubricating oil from the crankcase into the combustion chamber.
- Ensuring an exactly defined thickness of lubricating film on the cylinder wall.
- Distributing the lubricating oil over the cylinder wall.
- Stabilising the piston movements (piston rocking), in particular whenever the engine is cold and the running clearance of the pistons in the cylinder bore is still great.
- Heat transfer (heat dissipation) from the piston to the cylinder bore.

Characteristics:

- Low frictional resistance to prevent excessive loss of engine performance.
- Good stability and wear resistance against thermo-mechanical fatigue, chemical attack and hot corrosion.
- The piston ring should not cause any excessive wear to the cylinder bore, because the engine‘s service life has been greatly reduced.
- Long service life, operational safety and cost effectiveness throughout the entire operating time.

In addition, piston rings have further essential tasks which are described from of Chapter “1.6. Functions and Characteristics”.

1.2.1

Sealing of combustion gases

The main task of compression rings is to prevent the passage of combustion gas between piston and cylinder wall into the crankcase. For the majority of engines, this objective is achieved by two compression rings which together form a gas labyrinth.

For design reasons, the tightness of piston ring sealing systems in combustion engines is below 100%; as a result a small amount of blow-by gases will always pass by the piston rings into the crankcase. This is however a normal state which cannot be completely avoided due to the design. It is essential though, to prevent any excessive transfer of hot combustion gases past the pistons and cylinder wall. Otherwise this would lead to power loss, an increase of heat in the components as well as a loss of lubricating effects. The service life and the function of the engine would consequently be impaired. The various ring and sealing functions as well as the produced blow-by gas emission are addressed in the following chapters.

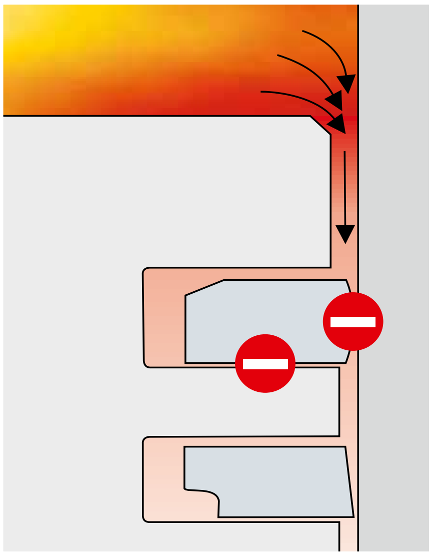


Fig. 1

1.2.2

Scraping and distributing oil

Next to sealing the area between the crankcase and combustion chamber, the piston rings are also used to control the oil film. The oil is uniformly distributed onto the cylinder wall by the rings. Most excess oil is removed by the oil control ring (3rd ring), although the combined scraper-compression rings (2nd ring) also remove the oil.

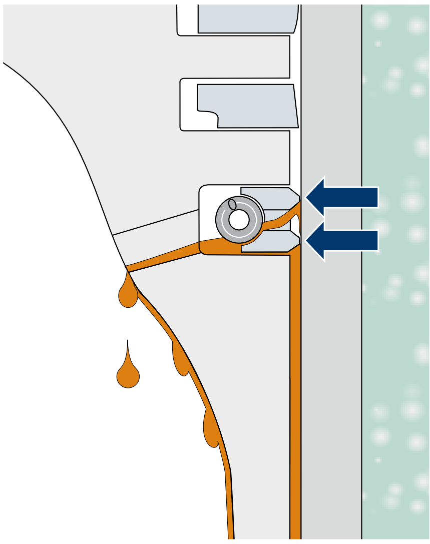


Fig. 2

1.2.3

Heat dissipation

Temperature management for the piston is another essential task of the piston rings. The major portion of the heat absorbed by the piston during the combustion process is dissipated by the piston rings to the cylinder surface. The compression rings, in particular, are significantly involved in heat dissipation. 50% of the combustion heat absorbed by the pistons is already dissipated to the cylinder wall by the upper compression ring (depending on the engine type).

Without this continuous heat dissipation by the piston rings, a piston seizure in the cylinder bore would occur within a few minutes or the piston even melt. From this perspective, it is evident that the piston rings must always have proper contact to the cylinder wall. Whenever out-of-roundness is caused in the cylinder bore or if the piston rings are jammed in the ring groove (carbonfouling, dirt, deformation), it will only be a matter of time until the piston suffers from overheating due to a lack of heat dissipation.

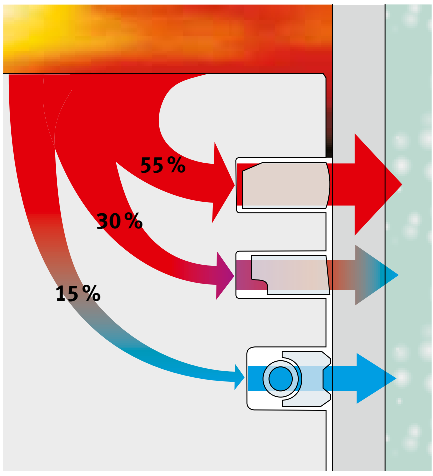
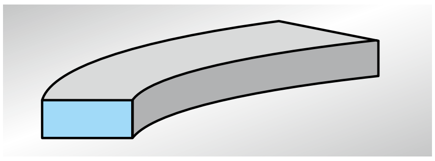


Fig. 3

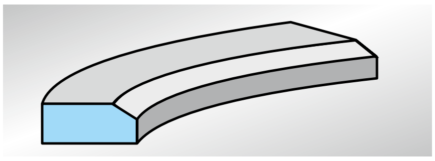
1.3.1
Compression rings

Fig. 1

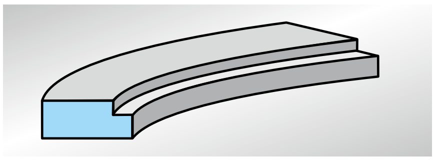
Rectangular rings



Rectangular ring



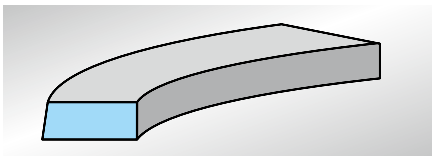
Rectangular ring with inside bevel



Rectangular ring with inside step

The term rectangular ring relates to rings with a rectangular cross section. Both ring sides are parallel to each other. This ring type is the simplest kind of compression ring and the most widespread.
Nowadays, it is predominantly used as first compression ring on all petrol engines for passenger cars and sometimes also on diesel engines for passenger cars. Inside bevels and inside steps cause the ring to twist in its installed (tightened) condition. The position of the bevel or the inside step on the upper edge produces a "positive ring twisting". Details on the exact effects of this twisting are given in, see chapter 1.6.9 Ring twisting.

Compression rings with oil scraping function



Taper faced ring

These rings have a double function. They support the compression ring when sealing off the gas and the oil control ring when regulating the oil film.

Important note:
Taper faced rings are used on all type of engines (passenger cars, utility vehicles, petrol and diesel engines), mostly in the second ring groove.

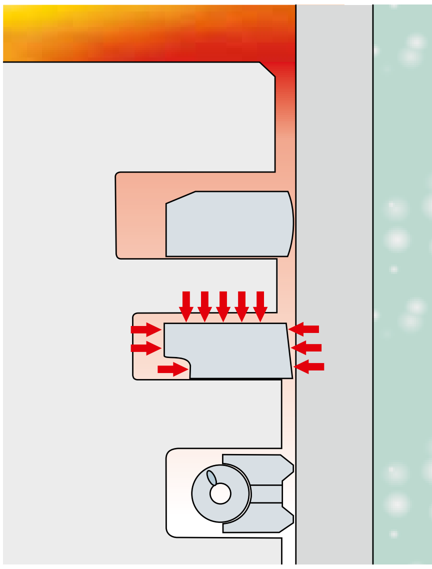


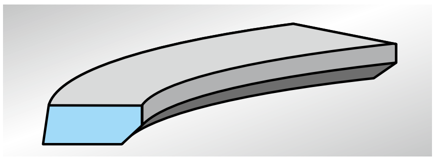
Fig. 2

The contact surface of taper faced rings is conical. The angular deviation related to the rectangular ring is between approx. 45 and 60 angular minutes, depending on the version. Due to its shape, the ring in its new condition only supports at the lower edge and as a result, is only in contact with the cylinder bore at a certain point. This brings about a high mechanical surface pressure in this area and a desired removal of material. Even after a short runtime, this intentional running-in wear results in a perfect round shape and, consequently, in an excellent sealing effect. After a prolonged runtime of some 100,000 miles, the conical contact surface is removed as a result of wear, so that the taper faced ring rather performs the function of a rectangular ring. The ring formerly produced as a taper faced ring now does a good sealing job as a rectangular ring.

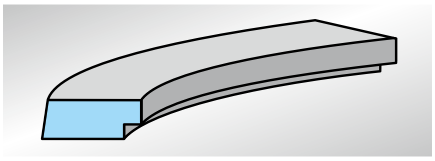
The fact that the gas pressure also acts on the ring from the front (the gas pressure can enter the sealing gap between cylinder wall and piston ring contact surface) slightly reduces the gas pressure reinforcement so that a slightly reduced contact pressure is applied during the run-in time of the ring and running-in is smoother with less wear (Fig. 2).

Taper faced rings also have good oil scraping properties in addition to their function as a compression ring. This is a result of the recessed upper ring edge. During the upstroke from the bottom to the top dead centre, the ring slides on the oil film, and thus floats a bit on the cylinder surface due to the hydrodynamic forces (formation of lubricating wedge). During the movement in the opposite direction, the edge penetrates deeper into the oil film and scrapes off the oil, mainly into the direction of the crankcase. Taper faced rings for petrol engines are applicated inside the first ring groove.

The position of the bevel or inside step on the lower edge causes a negative ring twist in this case (see chapter 1.6.9 Ring twisting).

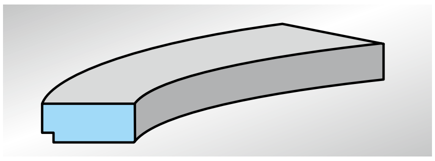


Taper faced ring with inside bevel at the lower edge



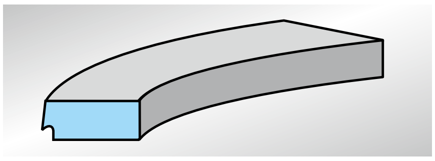
Taper faced ring with inside step at the lower edge

Napier rings



Napier ring

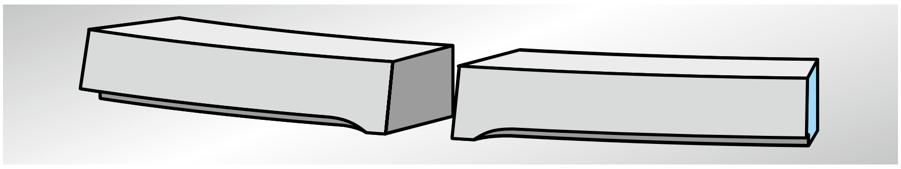
On the napier ring the lower edge of the piston ring sliding surface has a rectangular or an undercut recess, which not only seals off the gas, but also acts as an oil scraper. The recess forms a certain volume in which the scraped-off oil can gather prior to returning to the oil pan. In the past, napier rings were used as second compression rings on many vehicle engines. At present, taper faced napier rings are mainly used instead of napier rings. Napier rings are also used in compressor pistons for air brake systems, in particular as a first compression ring.



Taper faced napier ring

The taper faced napier ring is an advancement of the napier ring. The oil scraping effect is enhanced by the tapered sliding surface.

On piston compressors, the taper faced napier ring is not only fitted in the second but also in the first ring groove.



Taper faced napier ring with closed joint

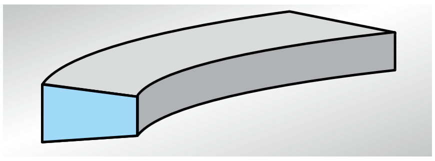
The circumferential nose stops before the joint end, thus improving the gas sealing function. Compared to the normal taper faced napier ring, this reduces the blow-by gas emission (see also 1.6.5. Closed gap clearance).

Keystone rings

Keystone rings or half keystone rings are used to prevent any carbon deposits in the ring grooves and therefore to counteract any seizing-up of the rings in the ring grooves. In particular when extremely high temperatures are produced even inside the ring groove, there is the hazard that the engine oil in the ring groove will carbonise due to the temperature exposure. On diesel engines, soot may be generated in addition to a potential oil coking, which also encourages deposits in the ring groove. If the piston rings seize-up as a consequence of deposits in the groove, the hot combustion gases can flow unimpeded between the piston and cylinder wall, thereby heating them up.Piston head melting and severe piston damage would result. Due to higher temperatures and soot formation on diesel engines, the keystone ring is preferably used in the first ring groove, but sometimes also in the second groove.

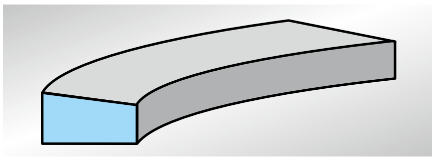
Attention

Keystone rings (half or full) should not be used in normal rectangular grooves. Whenever keystone rings are used, the ring grooves to be fitted on the piston must always have the appropriate shape.



Full keystone ring

On keystone rings, the two flanks of the ring are not parallel but are trapezoidal to each other. The angle is normally 6 °, 15 ° or 20 °.



Half keystone ring

On half keystone rings, the lower flank has no angle and is at right angles to the piston ring sliding surface.

Cleaning function

Due to the shape of the keystone rings and their movement in the ring groove as a result of piston rocking (see chapter 1.6.11. Piston ring movements) carbon deposits are mechanically ground away.

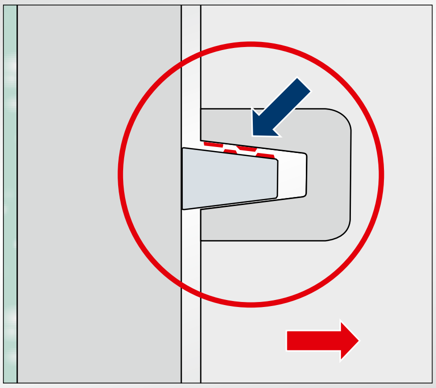


Fig. 1

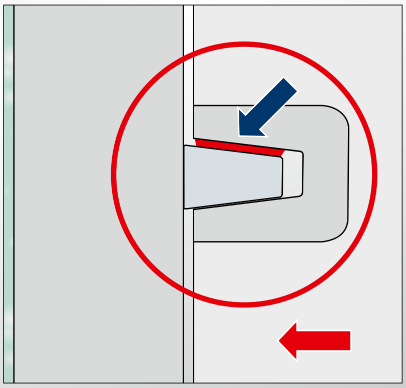


Fig. 2

1.3.2

Oil control rings

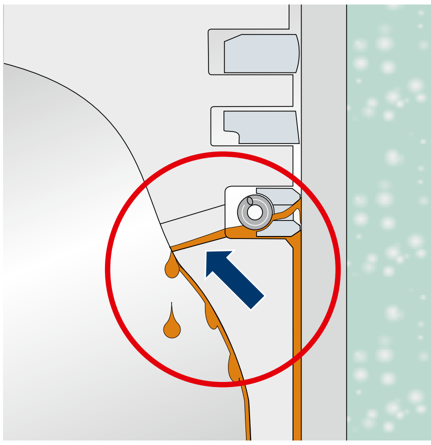


Fig. 1

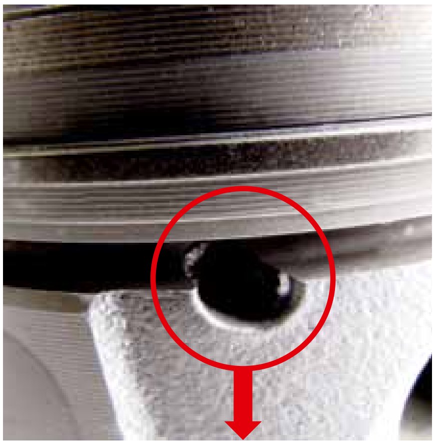


Fig. 2

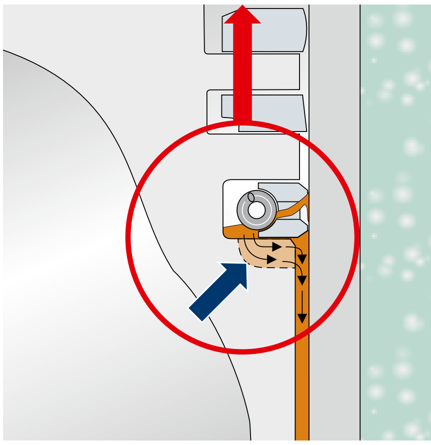


Fig. 3

Function:

Oil control rings are designed for the sole purpose of distributing oil on the cylinder wall and scraping excessive oil off the cylinder wall. Oil control rings usually have two scraping lands for improving their sealing and scraping functions. Each of these lands scrapes excessive oil off the cylinder wall. A certain volume of oil is produced both on the lower edge of the oil control ring and between the lands, which must be removed from the vicinity of the ring. As far as the rocking movement of the piston inside the cylinder bore is concerned, the smaller the distance between the two ring lands, the better the sealing function.

It is essential that the oil volume, which is scraped off the upper scraping land and accumulates between the lands, is removed from this area, as otherwise it may reach the top of the oil control ring where it must be scraped off by the second compression ring. For this purpose, one- and two-piece oil control rings are either provided with longitudinal slots or bores between the ring lands. The oil scraped off the upper land is directed through these holes in the ring body to the rear of the ring.

The scraped oil can be drained from there by different ways. One method is to direct the oil through the bore in the oil scraping groove to inside the piston so that it can drip back into the oil pan from there (Fig. 1). With so-called cover-slots (Fig. 2 and 3), the scraped oil is returned through the recess around the piston pin boss on the outer side of the piston. However, a combination of both versions is also used.

Both versions are well-proven for draining the scraped oil. Depending on the piston shape, combustion process or the intended application, either version can be used. A general statement cannot be made in favour of one or the other version on a mere theoretical basis. The decision as to which method is better suited for the respective piston is therefore taken on the basis of practical test runs.

Important note:

On two-stroke engines, the lubrication of the piston is effected using a lubrication mixture. Due to the design, there is no need for an oil control ring to be used.

Ring Types:

One-piece oil control rings

One-piece oil control rings are no longer used in modern engine manufacture. One-piece oil rings obtain their tension solely from the piston ring cross section. These rings are thus relatively rigid and have a less favourable form matching capability and, as a result, a suboptimal sealing behaviour than multi-piece oil control rings. One-piece slotted oil control rings are of grey cast iron.

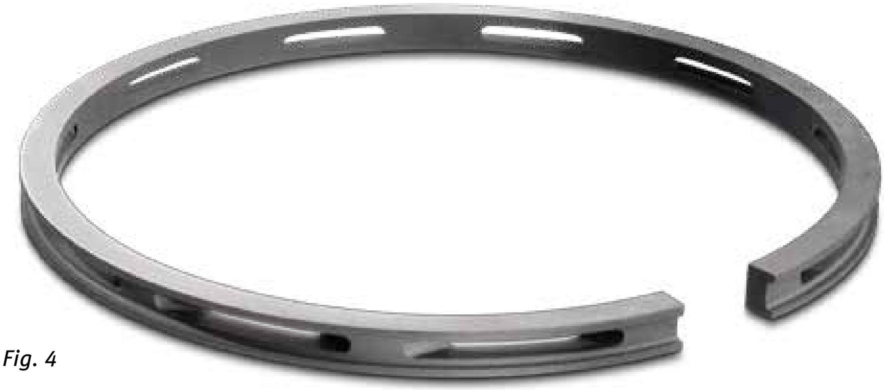
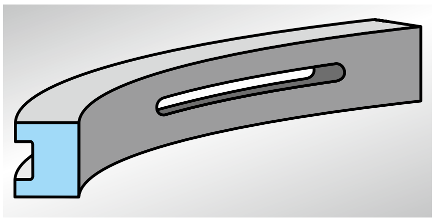
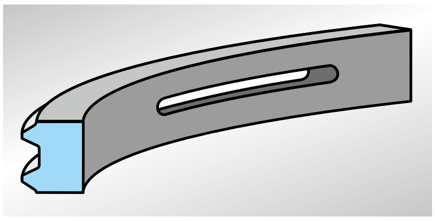


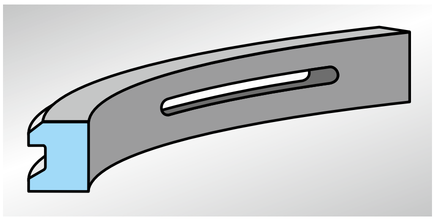
Fig. 4



Slotted oil control ring
Basic version with rectangular scraping lands and slots for draining oil.



Double-bevelled oil control ring
Compared to the slotted oil control ring, both edges of the sliding lands are chamfered to achieve an improved surface pressure.



Top bevelled oil control ring
The lands of this ring are only chamfered on the combustion chamber side. This results in a stronger oil scraping effect during the downstroke of the piston.

Two-piece oil control rings (spiral expander type)

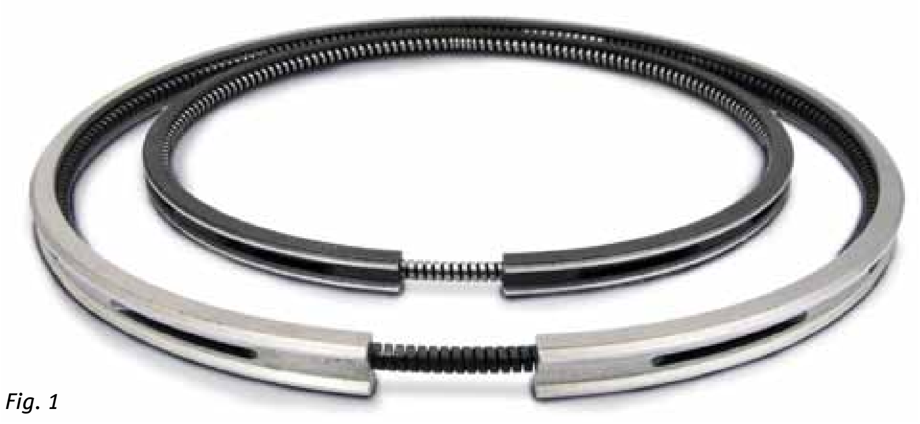


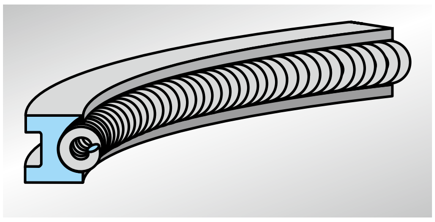
Fig. 1

Two-piece oil control rings comprise a ring body and a spiral spring arranged behind. The ring body has a significantly smaller cross section compared to the one-piece oil control ring. As a result, the ring body is relatively flexible and has an excellent form matching capability. The bed of the spiral expander on the inside of the ring body is either semi-circular or V-shaped.

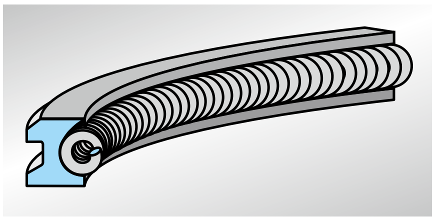
The actual tension is provided by a coil spring made out of heat-resistant spring steel which rests behind the ring and presses it against the cylinder wall.
In operation, the springs adhere closely to the rear end of the ring body, forming a unit. Although the spring is not twisted against the ring, the entire ring unit turns freely in the piston ring groove - the same as other rings. The radial pressure distribution with two-piece oil control rings is always symmetrical, because the contact pressure along the entire perimeter of the spiral spring is always identical (for more information see also Chapter 1.6.2 Radial pressure distribution).

To increase the service life, the outer diameter of the springs are ground, coiled tighter at the ring joint or even coated with a Teflon hose. Thanks to these measures, the frictional wear between ring body and spiral spring is reduced. The ring bodies of two-piece rings are made of either grey cast iron or steel.

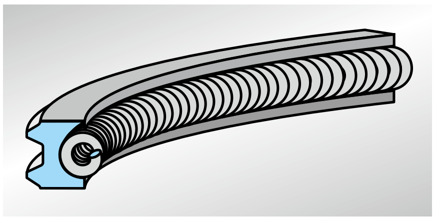
Important note:
The free gap – this is the distance between the joint ends of the ring body in its dismantled state without the expander spring arranged behind - is insignificant on multi-piece oil control rings. In particular on steel rings, the free gap can be practically zero. This is however neither a deficiency nor a reason for complaint.



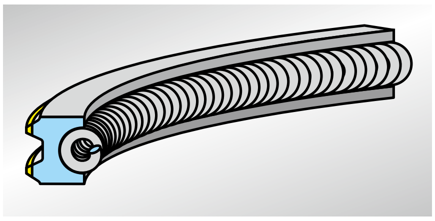
Slotted oil control ring with spiral expander
Basic version with better sealing effect than on a one-piece slotted oil control ring.



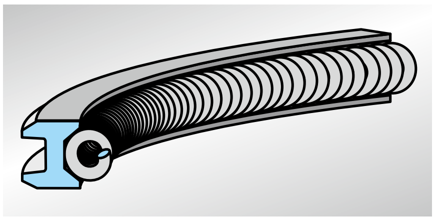
Spiral expander top-bevelled oil control ring
Same shape of sliding surface as a top-bevelled oil control ring, however with improved sealing effect.



Double-bevelled spiral expander ring
Same shape of sliding surface as a double-bevelled oil control ring, however with improved sealing effect. This is the most common oil control ring and can be used in any type of engine.



Double-bevelled spiral expander ring with chromium-plated lands
Same characteristics as for the double-bevelled spiral expander ring, but with increased wear resistance, and consequently, a longer service life. It is especially suited for diesel engines.



Double-bevelled spiral expander ring made of nitride steel
This ring is made of a wound strip of a profiled sectional steel and is provided with an antiwear protective coat on all sides. It is extremely flexible and less susceptible to fracture than the cast iron rings mentioned above. The oil drainage between the rails is made through stamped round orifices. This type of oil control ring is mainly used on diesel engines.

Three-piece oil control rings

Three-piece oil control rings are made of two lamellas which are pressed against the cylinder wall by a spacer and expander spring. Steel rail oil control rings are available either with chromium-plated sliding surfaces or nitrided on all sides. The latter contribute to improving the wearing properties of the sliding surface as well as between and the rails (secondary wear). Three-piece oil control rings have an excellent form matching capability and are mainly used on petrol engines for passenger cars.

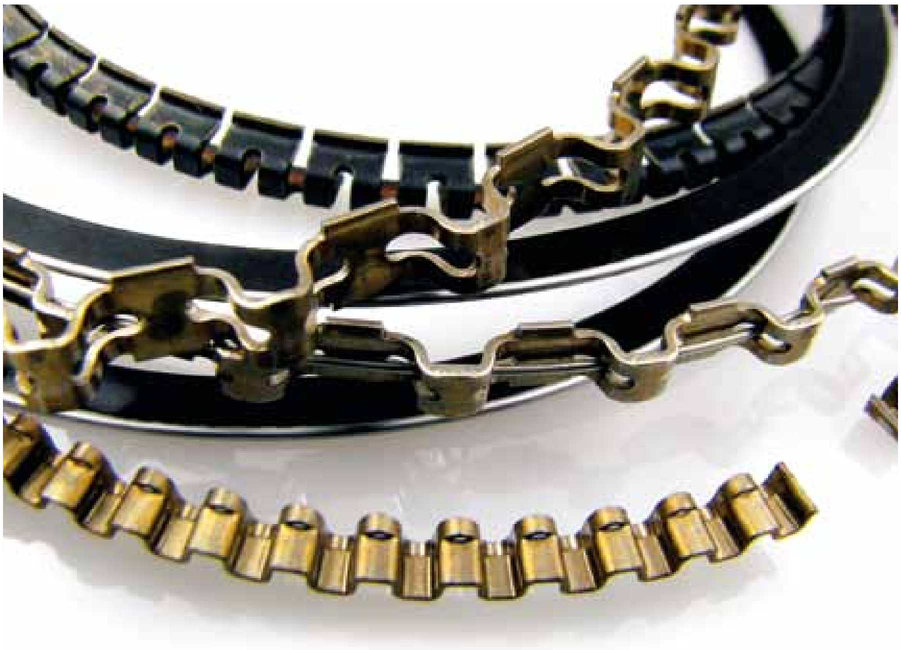
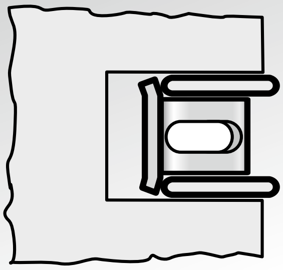


Fig. 1

Installation condition



Various expander spring versions

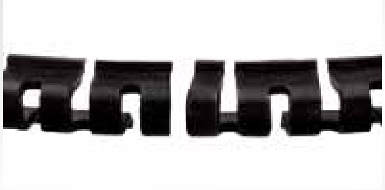


Fig. 2

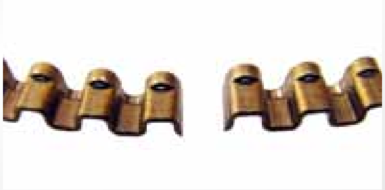


Fig. 4

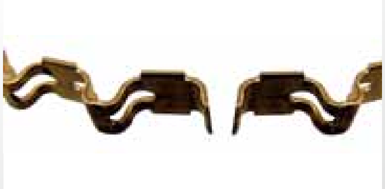


Fig. 3

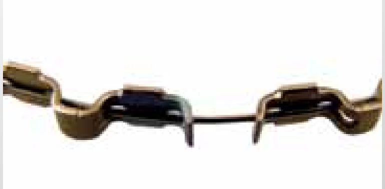


Fig. 5

1.3.3

Typical piston ring assembly

The complex requirements made on piston rings cannot be met by one piston ring alone. This can only be achieved by combining several piston rings of various designs. In present-day vehicle engine manufacture, a combination of compression ring, combined compression and scraper ring and a simple oil control ring has prooved the best results in practice (Fig. 6). Nowadays, pistons with more than three rings are relatively rare. Using more than two compression rings does not improve the sealing quality, but rather increases the friction losses.

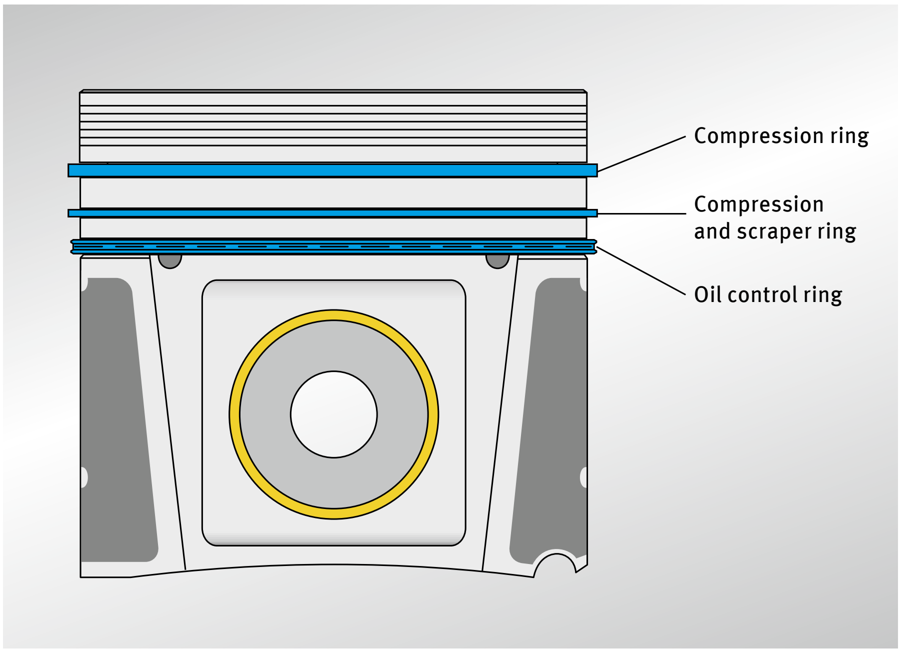


Fig. 6

1.3.4

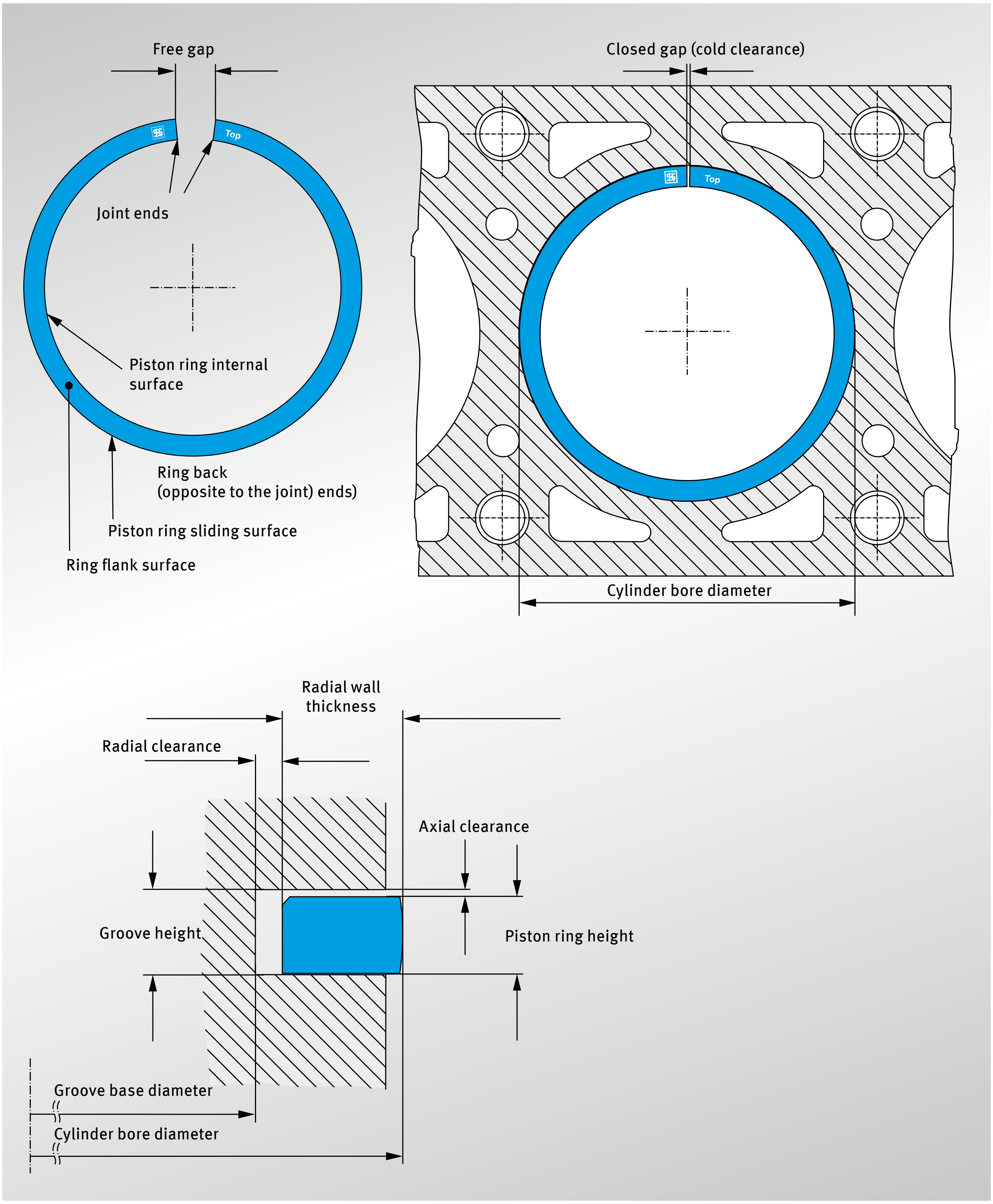
The “best” piston ring

There is neither the best piston ring, nor the best piston ring assembly. Each piston ring design is a “specialist” in its field. Each ring type and ring composition is ultimately a compromise between completely different, and sometimes opposing, requirements. Changing only one of the piston rings may unbalance the entire ring set matching. The final piston ring matching for an engine to be newly designed is always defined on the basis of extensive test runs conducted both on the test rig as well s under normal operating conditions. The following chart below does not claim to be complete, though it does show the effects of different ring characteristics on the various ring functions.

	Friction	Running-in	Service life
High ring tension	🔴	🟢	🔴
Low ring tension	🟢	○	🟢
Wear-resistant material		🔴	🟢
Softer material		🟢	🔴
Flat ring heights	🟢	○	🟢
Large ring heights	🔴	🟢	🔴

🟢 favourable - positive ○ medium - neutral 🔴 unfavourable - negative

1.4 | Piston ring designations



1.5.1

Piston ring materials

The materials for piston rings are chosen on the basis of running properties and conditions the piston rings are subjected to in operation. Good elasticity and corrosion resistance are as essential as high resistance against damage under extreme operating conditions. Even today, grey cast iron is still the main material for making piston rings. From a tribological viewpoint grey cast iron and the graphite inclusions in the structure present excellent dry-running properties (dry lubrication by graphite). These are of particular importance whenever the lubrication by engine oil is no longer warranted or the lubricating film is already destroyed. In addition, the graphite veins inside the ring structure function as an oil reservoir and thus counteract the destruction of the lubricating film under adverse operating conditions.

The following materials are used as grey cast iron materials:

- Cast iron with lamellar graphite structure (lamellar graphite cast iron), tempered and untempered.
- Cast iron with globular graphite structure (nodular cast iron), tempered and untempered.

Piston ring casting process

Chromium steel with martensitic micro structure and spring steel are used as steel materials. The surfaces are hardened to increase wear resistance. Hardening is generally done by nitriding*.

---

* Nitrogen hardening (nitriding) in technical jargon is also called nitrogenising (addition of nitrogen) and is a steel hardening process. Nitriding is normally carried out at temperatures between approx. 500 and 520 °C with treatment times from 1 to 100 hours. Diffusing nitrogen causes the formation of an extremely hard compound layer of iron nitride on the workpiece surface. Depending on the treatment time, this layer can be 10–30 µm thick. Common processes are salt-bath nitriding (e.g. crankshafts), gas nitriding (for piston rings) and plasma nitriding.

1.5.2

Surface coating materials

The sliding lands or sliding surfaces of piston rings can be coated to improve their tribological* characteristics. In this process, the main priority is to increase the wear resistance as well as to assure lubrication and sealing under extreme conditions. The coating material must harmonise both with the material of the piston ring and cylinder wall and the lubricant.

Surface coatings on piston rings are widely used. The rings of series engines are frequently provided with chromium, molybdenum and ferro-oxide.

But rings with CCC (chromium ceramic coating) and using the PVD process (physical vapour deposition process) are also used. Titan nitride (TiN) and chromium nitride (CrN) are applied in smaller production series (particularly in racing engines).

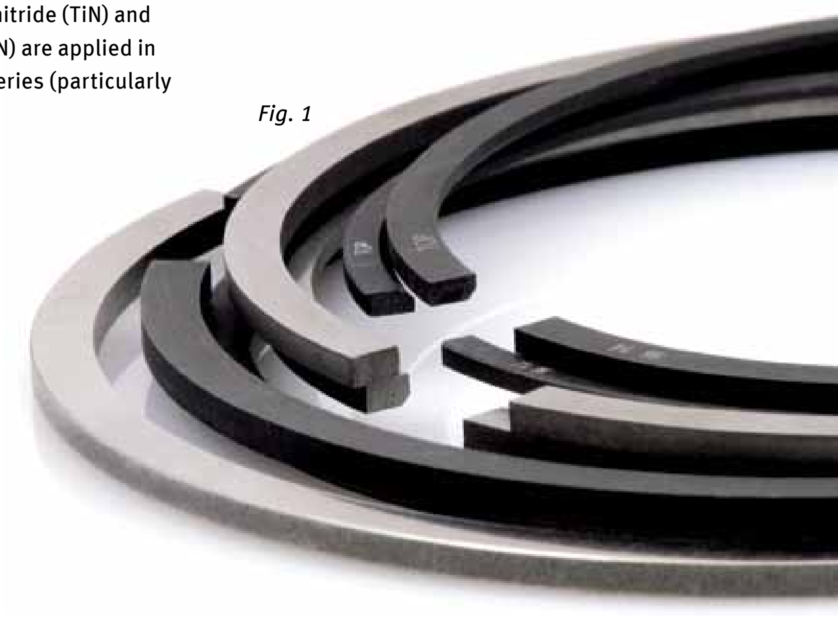


Fig. 1

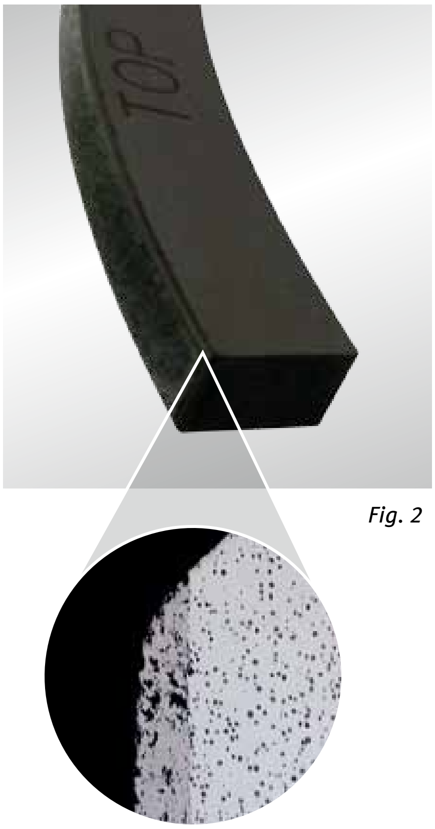


Fig. 2

Molybdenum coatings
To protect the rings against scuffing, the sliding surfaces of compression rings (not of oil control rings) can be filled or coated all over with molybdenum. Flame spraying or plasma spraying processes can be used for this purpose. Thanks to its high melting point (2620 °C), molybdenum warrants a very high temperature resistance. A porous material structure is also achieved as a result of the coating process. Engine oil can accumulate in the micro-cavities on the sliding surfaces of the rings (Fig. 2) ensuring that engine oil is still available for lubricating the piston ring sliding surface even under extreme operating conditions.

Properties:
- High temperature resistance
- Good dry-running properties
- Softer than chromium
- Less wear-resistant than chromium rings (more sensitive to dirt)
- More sensitive to ring flutter (molybdenum separation may be caused by extreme strain, such as for instance in the event of knocking combustion and other abnormal combustion conditions).

---

* Tribology (Greek: friction law) includes the field of research and the technology of interactive surface in relative movement. It deals with the scientific definition of friction, wear and lubrication.

Chromium plating
Chromium platings can be applied in galvanic processes as well as by plasma spraying. Galvanic coating is used for oil control rings.

Properties:

- Long service life (wear-resistant).
- Hard insensitive surface.
- Reduced surface (approx. 50 % compared to uncoated rings).
- Good resistance to burn marks.
- Reduced dry-running properties compared to molybdenum coatings.
- Thanks to it's good wear resistance, the run-in times are longer than with non-reinforced rings, steel rail oil control rings or U-Flex oil control rings.

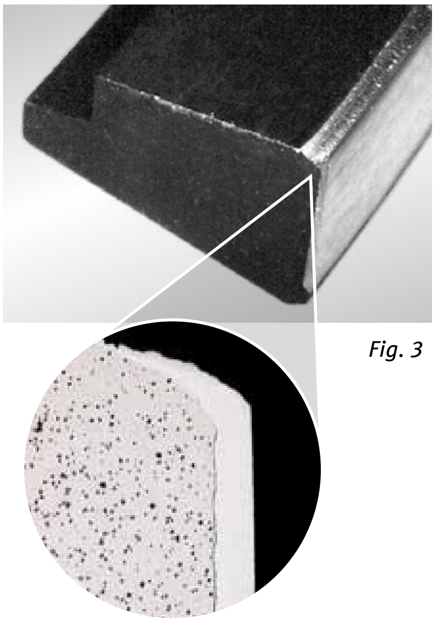
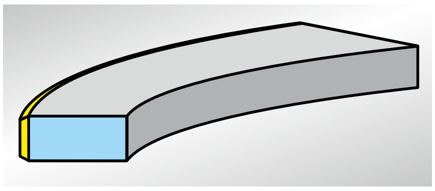


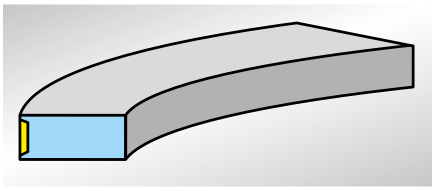
Fig. 3

1.5.3

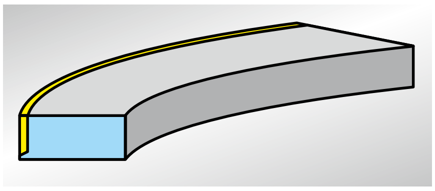
Coating versions on piston ring sliding surfaces



fully coated *Fig. 4*



chambered *Fig. 5*



chambered on one side *Fig. 6*

1.5.4

Separation of coatings

Cases of separated surface coatings appear from time to time on sprayed molybdenum and ferro-oxide coatings. This is mainly due to faults when installing the pistons (excessive expansion during fitment on the piston and fitment of the rings, as shown in Fig. 1). If the rings are incorrectly fitted on the piston, the coating will only break out of the back of the ring (Fig. 2). If the coating flakes off at the joint ends (Fig. 3), this indicates ring flutter due to abnormal combustion (e.g. knocking combustion).

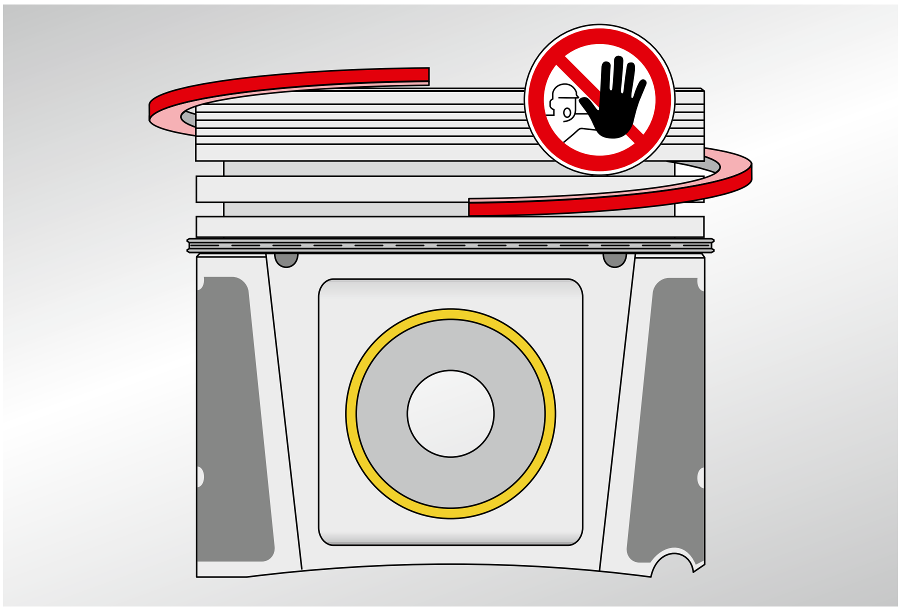


Fig. 1

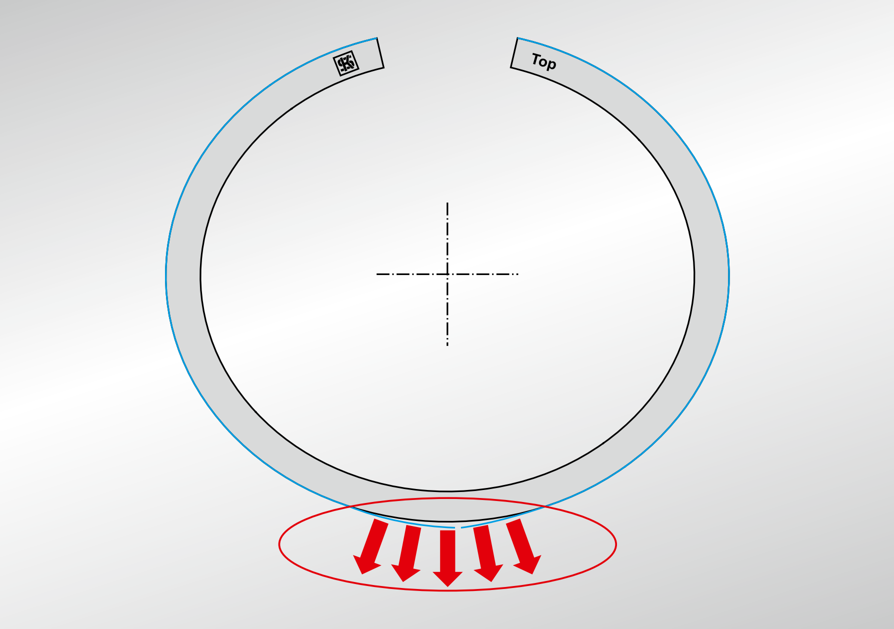


Fig. 2

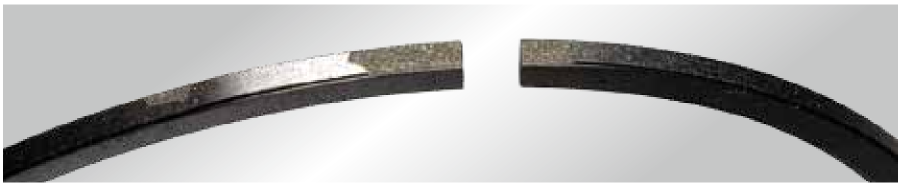


Fig. 3

1.5.5

Machining of sliding surfaces (lathe-cut, lapped, ground)

Cast iron piston rings are normally only fine-turned on their sliding surfaces. As a result of the short run-in time for non-reinforced rings, grinding or lapping the sliding surface is not required. If the surfaces are coated or hardened, the sliding surfaces are either only ground or also lapped. The reason for this is that, because of the high wear resistance, it would take a long time until the rings adopted a round shape and sealed properly. This would result in power loss and high oil consumption.

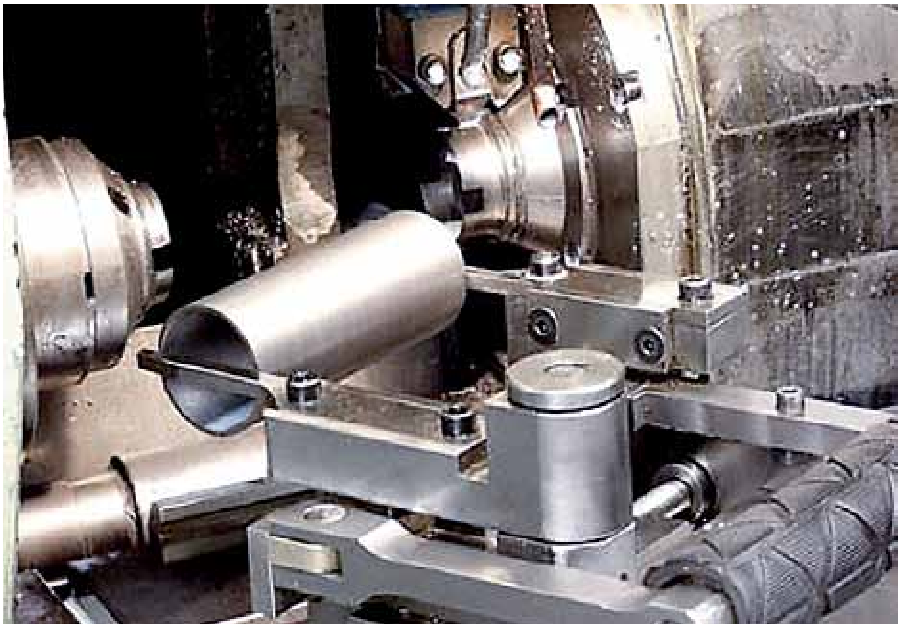


Fig. 4

1.5.6

Ball-shaped sliding surface shapes

Another reason for using grinding or lapping processes is the shape of the sliding surface. Due to up- and downstroke and the movement of the ring in the groove (ring twisting), rectangular piston rings adopt a ball-shape on their sliding surfaces after a while (Fig. 5 und 6). This has a positive effect on the formation of the lubricating film and the service life of the rings.

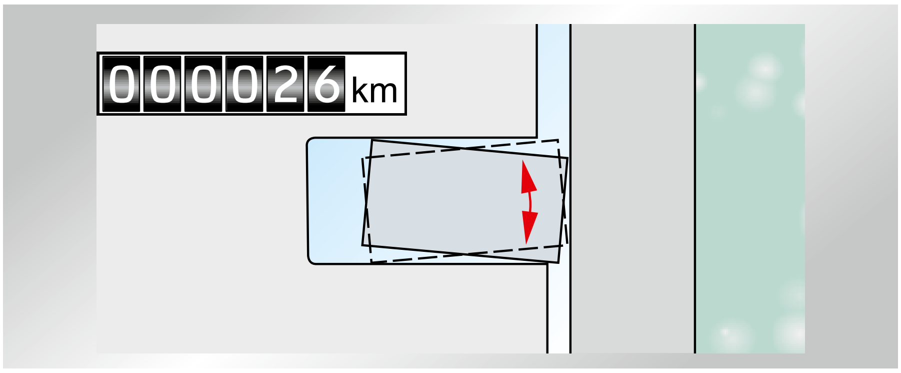


Fig. 5

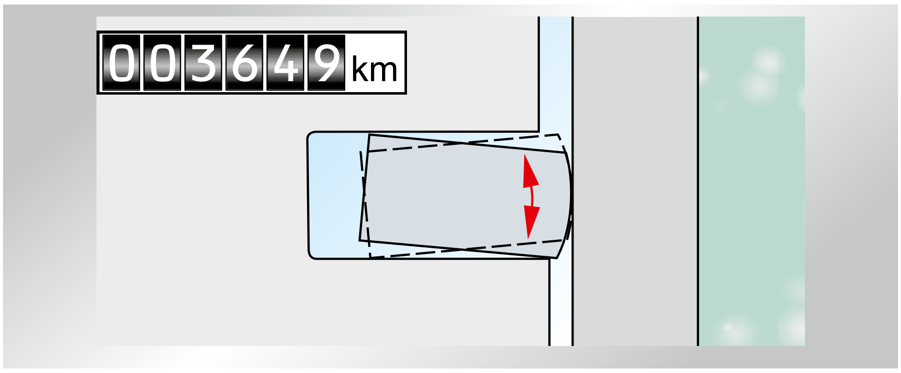


Fig. 6

1.5 | Structure and shape of piston rings

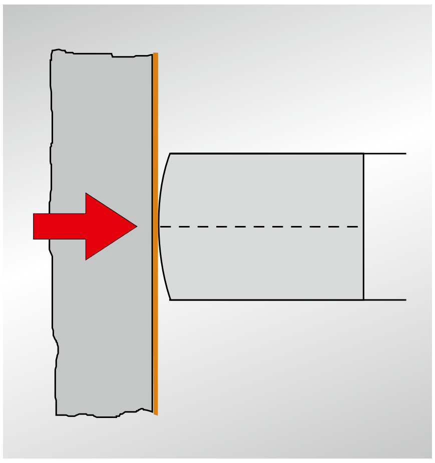


Fig. 1 - Symmetric convexity

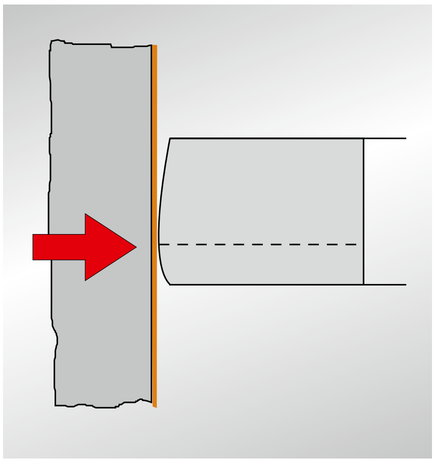


Fig. 2 - Asymmetric convexity

During the production process of coated rings, they are already given a slightly convex or ball-shaped. As a result, they do not have to gain their required shape by running-in, but have their specified shape and a practically run-in sliding surface from the outset. Consequently the high rate of run-in wear as well as the associated oil consumption is eliminated. Due to the contact of the piston ring sliding surface a certain point, a higher specific contact pressure on the cylinder wall is achieved and thus an improved gas and oil sealing effect. The risk of edge riding due to ring edges still sharp is also reduced. At any rate, chromium rings always have bevelled edges to prevent the oil film from pressing through during the run-in time. In some unfavourable cases, the extremely hard chromium layer could cause considerable wear and damage to the much softer cylinder wall.

Symmetric, ball-shaped piston ring sliding surfaces (Fig. 1), irrespective of whether caused by running in the engine or already during the ring production, have excellent sliding properties and generate a lubricating film of defined thickness. With symmetric convexity, the thickness of the lubricating film is uniform during the up- and downstroke of the piston. The forces acting on the ring and making the ring float on the oil film are the same in either direction.

If the convexity has already been created in the course of ring production, it is possible to create an asymmetric convexity to provide an improved control of oil consumption. The apex of the convexity will then not be in the middle of the sliding surface but slightly below it (Fig. 2).

The ring then slides properly on the oil film during the upstroke in the direction of the top dead centre, because as a result of the larger effective surface above the apex of the ring, the formation of the lubricating wedge is, larger than below it (Fig. 3). The ring is pressed away from the oil film than more than vice versa. This means that the thickness of the lubricating film is not minimised as much during the upstroke. During the downstroke of the ring (Fig. 4), the ring cannot float on the oil film to the same extent because of the smaller effective surface below the apex. A larger quantity oil is scraped and returned to the crankcase. Asymmetrically convex shaped rings are therefore intended for controlling the oil consumption on diesel engines, in particular under unfavourable operating conditions. These occur for instance after longer idling periods following full-load operation, which frequently causes an ejection of oil into the exhaust tract and blue smoke emission upon accelerating again.

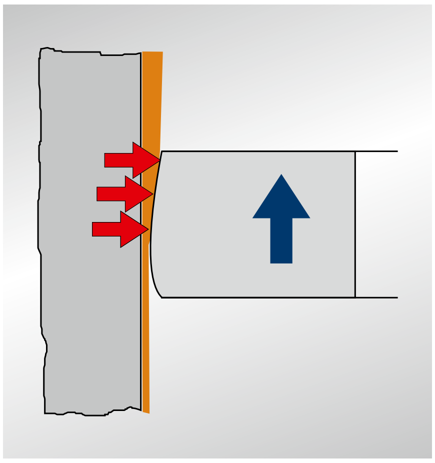


Fig. 3

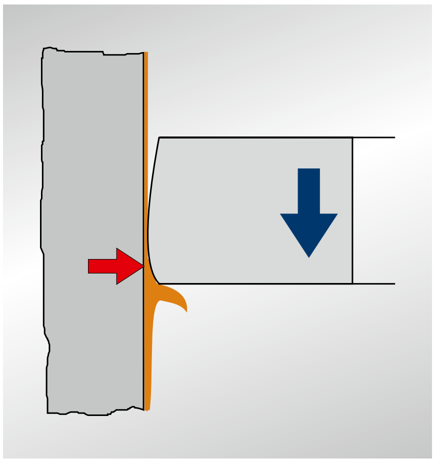


Fig. 4

1.5.7
Surface treatments

Depending on the design, the surfaces of piston rings can either be uncoated, phosphated or copperplated. This only affects the corrosion behaviour of the rings. Although uncoated rings are nice and shiny in their new condition, they are completely unprotected against rust formation. Phosphated rings have a dull black surface and are protected against rust formation by their phosphate coat.

Copperplated rings are also well protected against corrosion and provide some protection against the formation of scuff marks during the running-in process. The copper has a certain dry lubricating effect and, consequently minimum dry-running properties during run-in.

However, these surface treatments do not affect the function of the rings. The colour of piston ring does not make any difference to its quality.

1.6.1

Tangential tension

Piston rings have a larger diameter in their untensioned condition than when fitted. This is required to apply the requested all-side contact pressure in the cylinder bore.

The measurement of the contact pressure in the cylinder bore is quite difficult in practice. The diametral load which presses the ring against the cylinder wall is therefore determined with the aid of a formula for tangential force. The tangential force is the force requir ed to contract the joint ends until the joint clearance is achieved (Fig. 1). The tangential force is measured by means of a flexible steel strip which is laid around the ring. This strip is then contracted until the specified joint clearance of the piston ring is achieved. The force can then be read on the force-measuring device. The measurement of oil control rings is always carried out when the expander spring has been inserted. To ensure precise measurements, the measurement set-up is subjected to vibrations to enable the expander spring to adopt its normal shape behind the ring body. The design of three-piece steel-rail expander rings also requires the ring package to be axially fixed, because the steel rails would otherwise escape to the side and render the measurement impossible. Figure 2 shows a diagram of tangen tial force measurement.

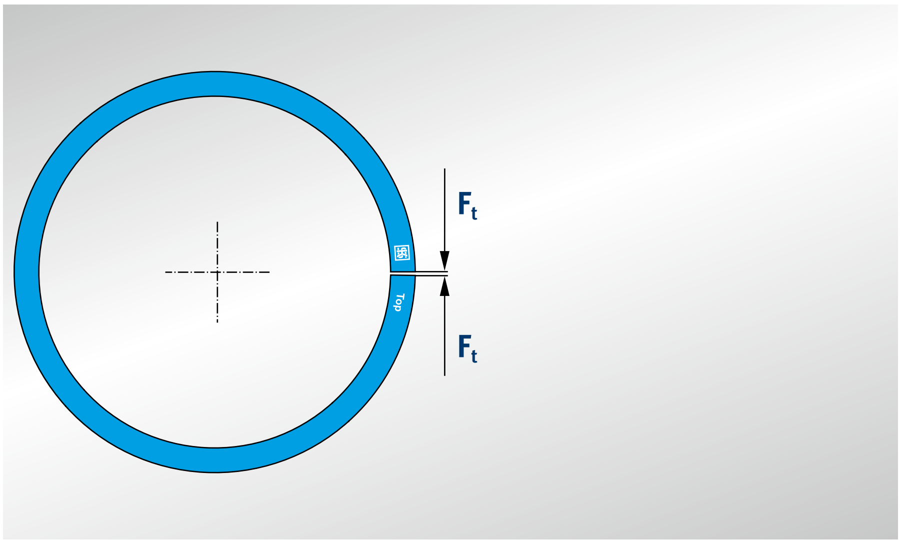


Fig. 1

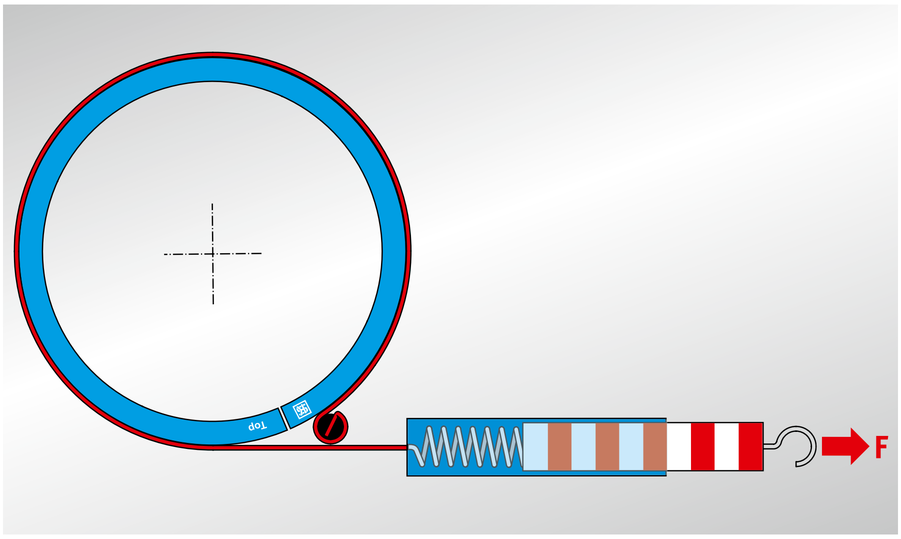


Fig. 2

Important note:
Piston rings lose their tangential tension due to radial wear caused by mixed friction or longer service life. Measuring their tension is only meaningful on new rings on which the cross section is still complete.

1.6.2

Radial pressure distribution

The radial pressure depends on the modulus of elasticity of the material, the free gap in the untensioned condition and, not least, on the cross section of the ring. There are two main distinguishing features for radial pressure distribution. The basic feature is the symmetric radial pressure distribution (Fig. 3). This occurs mainly on multipiece oil control rings consisting of a flexible ring carrier or steel rails with a relatively low internal stress. The expander spring arranged behind presses the ring carrier or the steel rails against the cylinder wall. The radial pressure acts symmetrically as a result of the expander spring which supports itself in its compressed condition (i.e. when installed) against the rear of the ring carrier or the steel rails.

On four-stroke engines, the symmetric radial pressure distribution is no longer used for compression rings. Instead, a pear-shaped distribution (positive oval) is applied to counteract the tendency of the ring joint ends to flutter at higher engine speeds (Fig. 4). Ring flutter always begins at the joint ends and is then induced along the entire ring circumference. Increasing the pressure force at the joint end counteracts this, since the piston rings are pressed more intensely against the cylinder wall in this section and, as a result, the ring flutter is efficiently reduced or stopped.

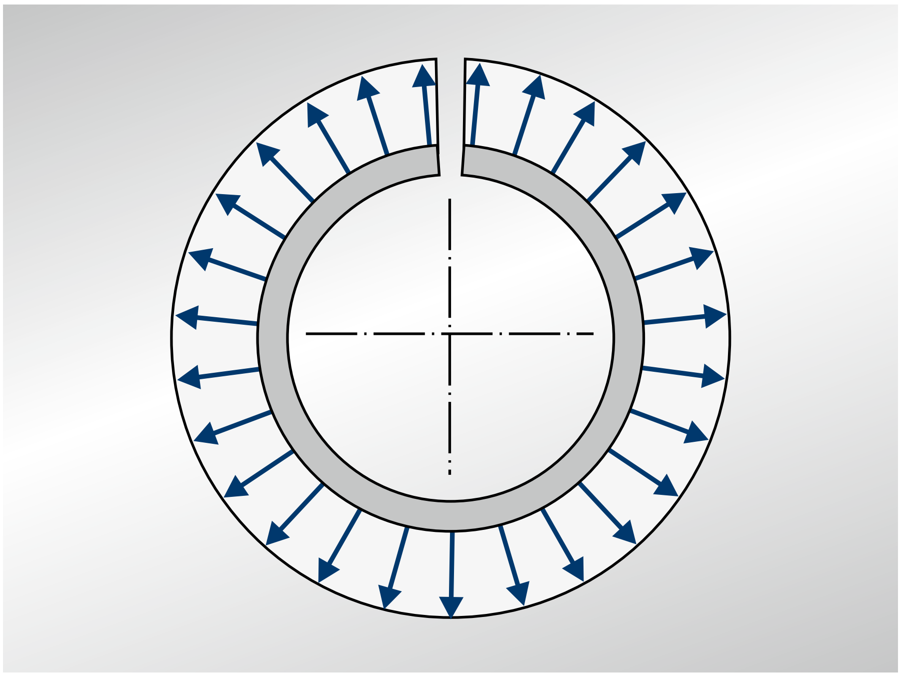


Fig. 3 - Symmetric radial pressure distribution

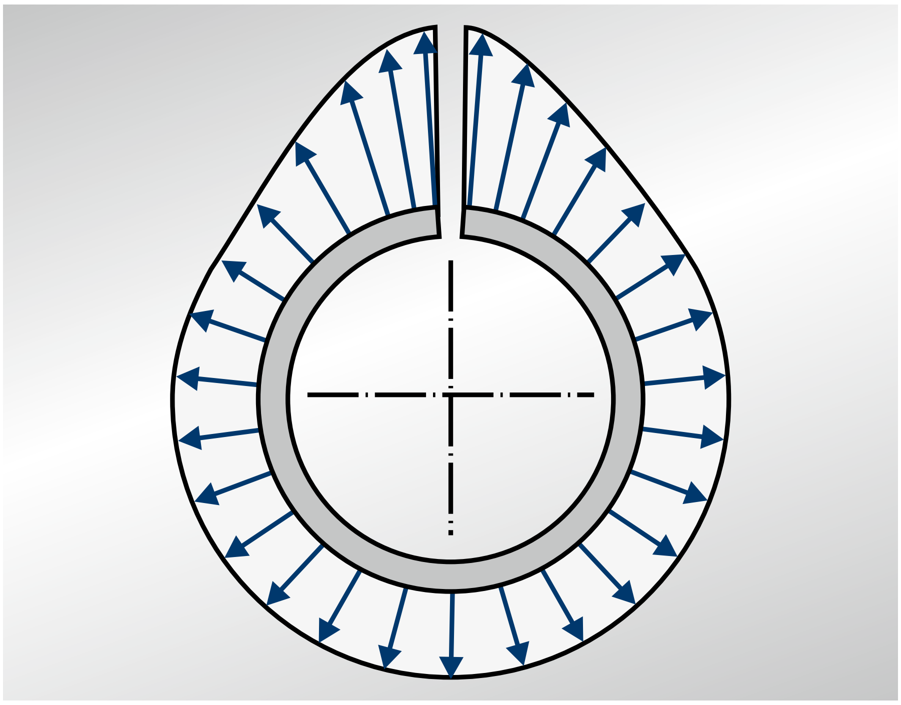


Fig. 4 - Positive oval radial pressure distribution

1.6.3

Contact pressure reinforcement due to combustion pressure

The contact pressure reinforcement resulting from the combustion pressure to which the compression rings are subjected during engine operation is, however, more important than the internal stress of the piston rings by far.

Up to 90% of the total pressure force applied by the first compression ring is generated by the combustion pressure during the combustion cycle. As shown in Fig. 1, the pressure is applied behind the compression ring pressing them even more against the cylinder wall. The contact pressure reinforcement mainly acts on the first compression ring and, to a reduced extent, also extends to the second compression ring.

The gas pressure for the second piston ring can be controlled by varying the joint clearance of the first compression ring. If the joint gap is slightly enlarged, for instance, more combustion pressure will reach the rear of the second compression ring, also resulting in an increased pressure force. With a higher number of compression rings, there is no contact pressure reinforcement from the second compression ring on due to the gas pressure from the combustion.

Mere oil control rings function due to their internal stress. Due to the specific shape of the rings, the gas pressure cannot act as a pressure amplifier in this case. The distribution of forces on the piston ring also depends on the shape of the piston ring sliding surface. If taper faced rings and ball-shape compression rings are used, the gas pressure also arrives in the sealing gap between piston ring sliding surface and cylinder wall and acts against the gas pressure applied behind the piston ring (see chapter 1.3.1 Compression rings).

The axial pressure force which is applied to the compression ring at the lower groove side is, however, only generated by the gas pressure. The internal stress of the rings does not act in the axial direction at all.

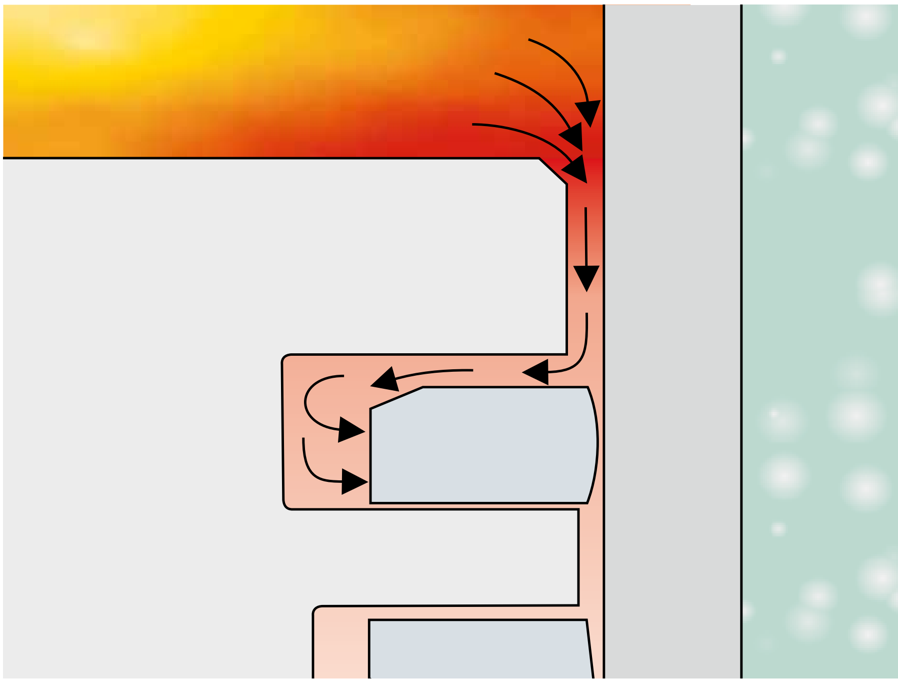


Fig. 1

Important note:
During idling, there is less contact pressure reinforcement of the rings by the gas pressure because the combustion chambers are not properly filled. This is especially noticeable on diesel engines. Engines that idle for extended periods have an increased oil consumption because the scraper effect is compromised by the lack of any support through gas pressure. Frequently, engines then eject blue clouds of oil out of the exhaust pipe when accelerating after a longer idling period; this is because oil was able to gather in the combustion chamber and exhaust tract and is not burnt until the driver accelerates again.

1.6.4

Specific contact pressure

The specific contact pressure depends on the ring tension and the contact area of the ring on the cylinder wall (F × A). If the specific pressure force is to be doubled-up, two options are available: either one doubles the ring tension or one halves the ring's contact surface in the cylinder. As can be seen in the illustration, the resulting force (specific pressure force = force × area) acting on the cylinder wall is always the same, although the ring tension has been doubled or halved, as the case may be.

On new engines the trends is towards lower ring heights because the objective is to reduce friction in the engine. However, this can only be accomplished by reducing the effective contact area between the ring and the cylinder wall. If the ring height is reduced by half, the piston ring tension, and consequently the friction, is reduced by half as well. Since the remaining force acts on a smaller area, the specific contact pressure on the cylinder wall (force × area) with half the area and half the tension remains as great as with double the area and double the tension.

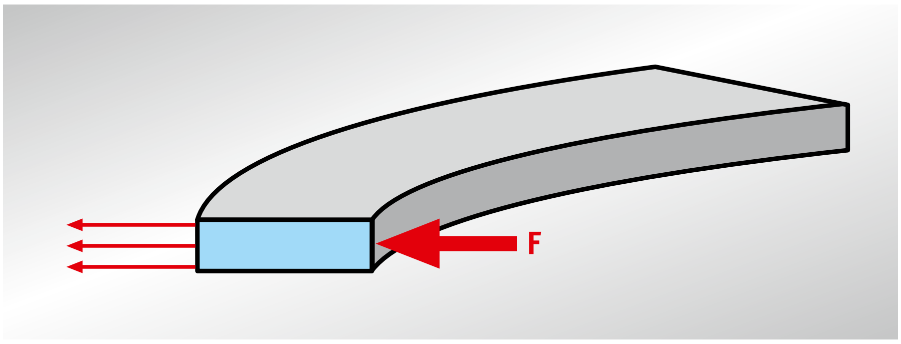


Fig. 2

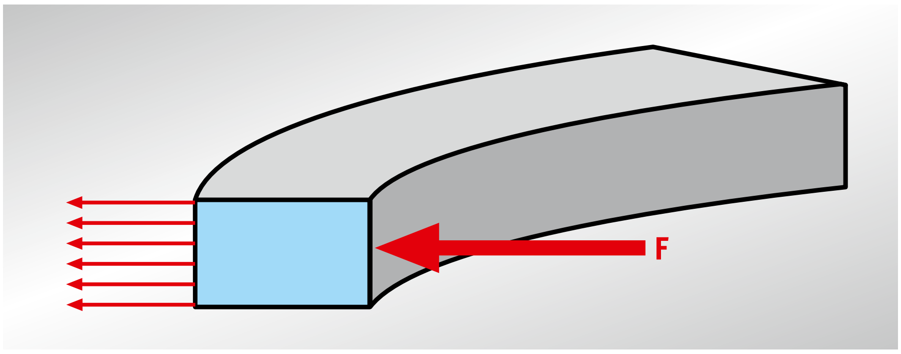


Fig. 3

Attention

The ring tension alone cannot be used for assessing the contact pressure and the sealing behaviour. When comparing piston rings, it is thus always necessary to consider the size of the sliding surface.

1.6.5

Closed gap clearance

The closed gap clearance is an essential constructional feature for ensuring the proper functioning of piston rings. It can be compared to the valve clearance of intake and exhaust valves. When ever the components are heated, the natural thermal expansion causes an extension of the length and/or the dia meter. Depending on the temperature difference between ambient and opera ting temperature, more or less cold clearance is necessary to ensure proper functioning at operating temperature.

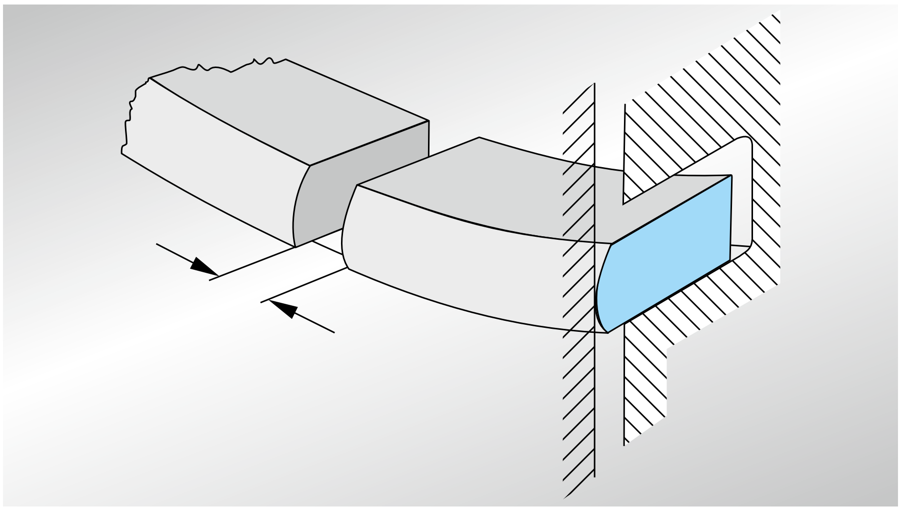


Fig. 1

A basic prerequisite for the proper functioning of the piston rings is that the rings can freely rotate in their grooves. If the piston rings seized in their grooves they could neither seal nor dissipate the heat. The joint clearance, which must be maintained even at operating temperature, ensures that the circumferential dimension of the piston ring always remains smaller than the circumference of the cylinder as a result of its thermal expansion. If the joint clearance were nullified by the thermal expansion, the joint ends of the piston ring would be pressed against each other. If further pressure were applied, the piston ring would even have to bend to compensate the change in length caused by heating. Since the piston ring cannot expand in its radial direction due to the thermal expansion, the change in length can only be compensated in the axial direction. Figure 2 shows how the ring will be deformed whenever the space in the cylinder bore is insufficient.

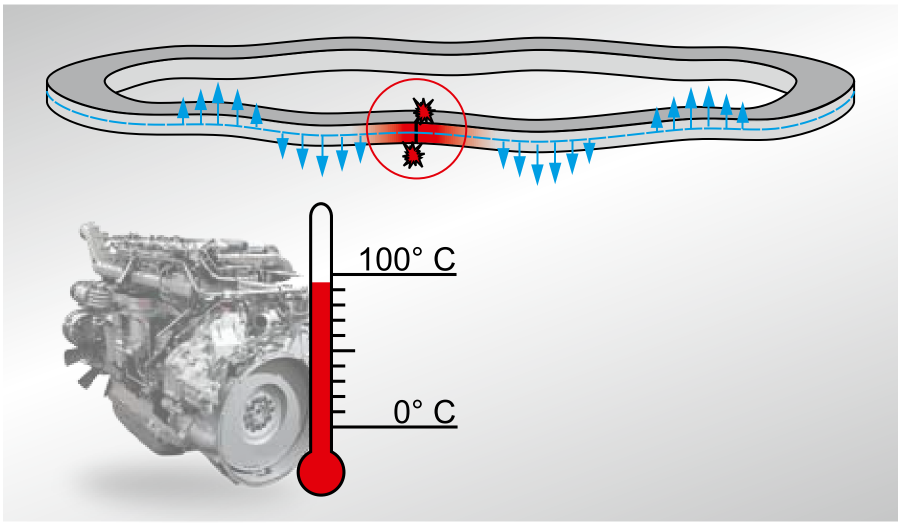


Fig. 2

The following calculation shows the change in the circumferential length of the ring at operating temperature using the example of a piston ring with a diameter of 100 mm.

Example of calculation:

Cylinder diameter	d	100 mm
Ambient temperature	t_1	20 °C
Operating temperature	t_2	200 °C
Coefficient of linear expansion of cast iron	α	0.000010

Circumference of piston ring

$U = d \times \pi$

$U = 100 \times 3.14 = 314$ mm

$U = l_1$

Change in length of piston ring at operating temperature

$\Delta l = l_1 \times \alpha \times \Delta t$

$\Delta l = l_1 \times \alpha \times (t_2 - t_1)$

$\Delta l = 314 \times 0.000010 \times 180 = 0.57$ mm

In this example, a joint clearance of at least 0.6 mm is required to ensure proper functioning. However, not only the piston and the piston rings expand, the diameter of the cylinder bore also increases when heated at operating temperature. This is the reason why the gap clearance can be slightly smaller again. However, the cylinder bore expands far less as a result of the thermal expansion than the piston ring. On the one hand, the structure of the cylinder block is more rigid than that of the piston; on the other hand the cylinder surface does not heat up nearly as much as the piston with its rings.

Furthermore, the diameter expansion of the cylinder bore due to the thermal expansion is not uniform along the entire running surface of the cylinder liner.The combustion's heat introduction means that the cylinder expands more in the upper area than it does in the lower area. The uneven thermal expansion of the cylinder bore will therefore result in a variance in the cylinder shape which will be slightly coneshaped (Fig. 3).

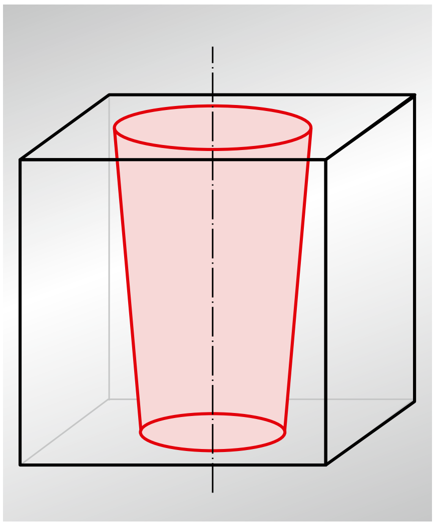


Fig. 3

1.6.6

Piston ring sealing faces

Piston rings do not only seal on the sliding surface but also on the lower flank. The sealing effect on the sliding surface is responsible for sealing the ring towards the cylinder wall; the lower groove side takes over the sealing of the rear end of the ring. Therefore, the ring requires not only good contact towards the cylinder wall, but also good contact to the lower groove side of the piston. If this contact is not given, oil or combustion gases may flow behind the ring.

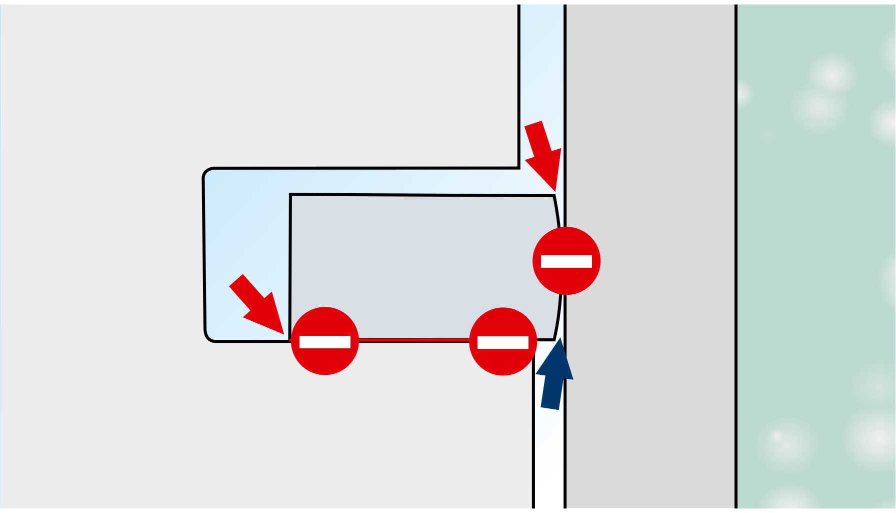


Fig. 1

With the aid of these illustrations, it is easy to imagine that, due to wear (dirt and long service life), the sealing on the rear end of the ring is no longer warranted which causes an increased transfer of gas and oil through the groove. It is therefore a hopeless venture to fit worn ring grooves with new rings. The unevenness on the groove side will no longer seal against the ring, and when the groove has expanded in height, it provides more space for ring movements. The fact that the ring is not properly guided in the groove due to excessive height clearance makes it much easier for the ring to lift off the groove side, to pump oil (Fig. 2 and 3), and also causes ring flutter and a loss of the sealing effect. Furthermore, excessive convexity on the sliding surface of the ring occurs, making the oil film too thick and causing increased oil consumption.

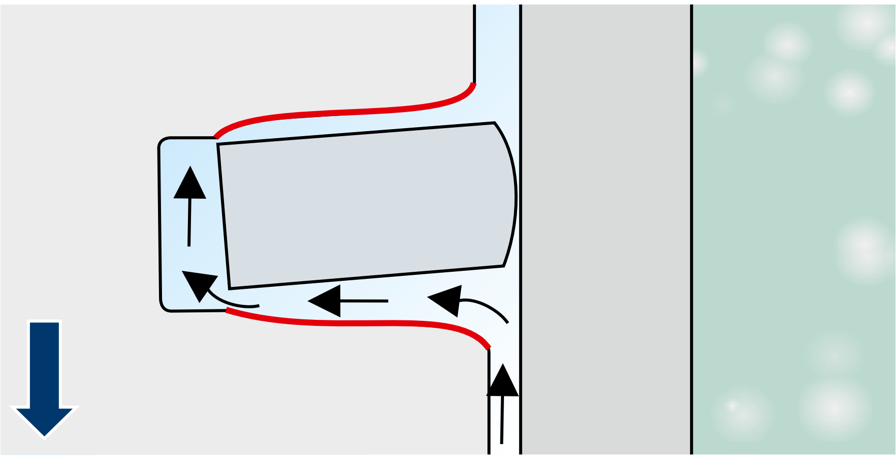


Fig. 2 - Intake cycle

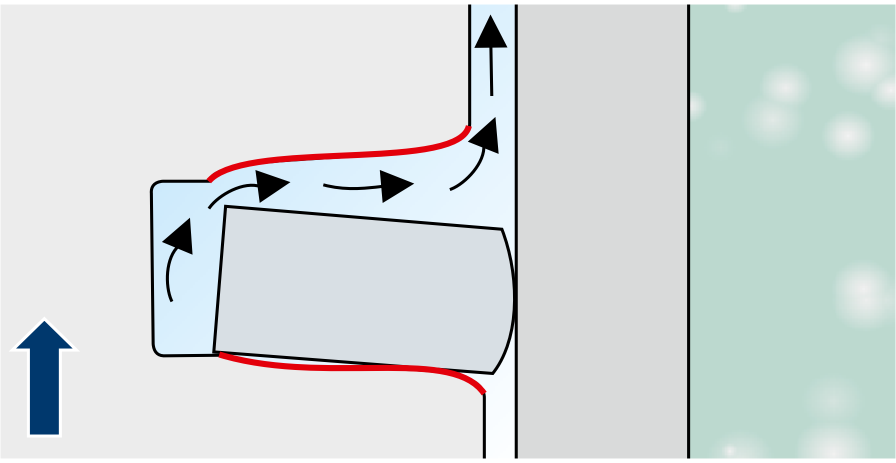


Fig. 3 - Compression cycle

1.6.7

Throttle gap and blow-by

Since - due to the design - it is not possible to achieve a 100% gas sealing with the piston rings used in engine manufacture, so-called blow-by gases are produced during engine operation. Combustion gases escape through the tiniest sealing gap into the crankcase, past the piston and piston rings. During this process, the volume of blow-by gases is determined by the size of the gas leakage area resulting from the joint clearance and half the piston running clearance. In contrast to graphics shown, the gas leakage area is, in reality, really tiny. As a rule of thumb for the maximum blow-by gas emission, about 1 % of the taken-in air quantity should be anticipated. Depending on the piston ring position, a greater or lesser volume of blow-by gases is produced during operation. If the joint clearances of the first and second compression ring are congruent in the piston ring grooves, the volume of blow-by gases is slightly greater. This occurs in operation at regular intervals, since the rings rotate in their grooves with quite a few revolutions per minute. If the joint clearances are placed exactly opposite each other, it is evident that the blow-by gas has a longer way to pass through the sealing labyrinth, thus causing less gas losses. Blow-by gas arriving in the crankcase is returned to the intake air system via the crankcase ventilation and conveyed to the combustion process. The reason for this is the harmful properties of the gases. These are rendered harmless thanks to recombustion in the engine. Crankcase ventilation is required because excess pressure in the crankcase would result in increased oil leakage on the radial shaft sealing rings of the engine. Increased blow-by gas emissions indicate either considerable wear of the piston ring after long running time, or the piston crown already shows signs of cracking allowing combustion gases to pass to the crankcase. But incorrect cylinder geometry (see Chapter 2.3.5 Cylinder geometry and roundness) will also result in increased blow-by gas emissions.

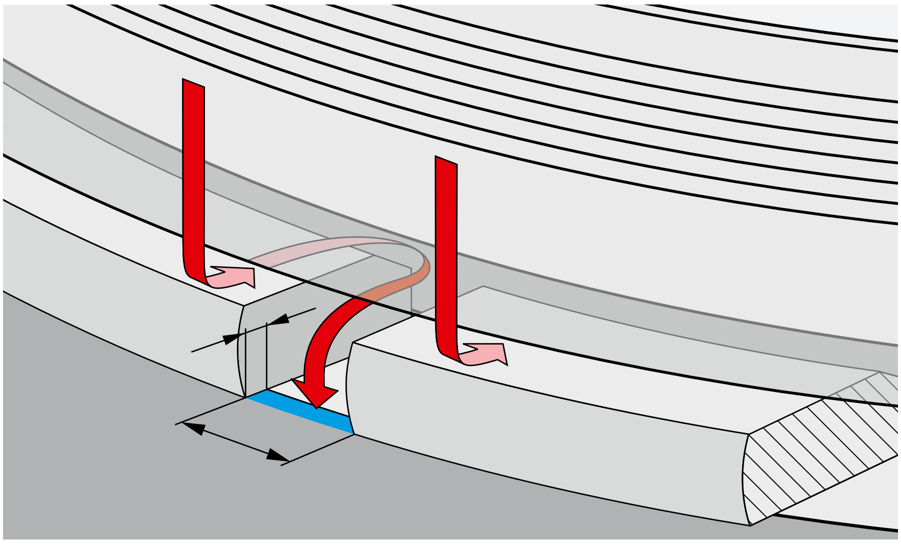


Fig. 4

On stationary engines or test-bench engines, the blow-by gas emission is regularly measured and monitored and used as a warning indicator for the occurrence of engine failure. Whenever the measured blow-by gas volume exceeds the maximum admissible value, the engine will shut-off immediately. Consequently, severe and costly engine failures can be prevented.

1.6.8

Ring height clearance

The ring height clearance (Fig. 1) is not a result of wear in the ring groove. The height clearance is a functional dimension that is vital if the piston rings are to function properly. The ring height clearance assures that the rings can move freely in their piston ring grooves (see also Chapter 1.6.11 Piston ring movements). The ring height clearance must be great enough to ensure that the ring does not jam at operating temperature and that sufficient combustion pressure can stream into the groove to pass behind the ring (see also Chapter 1.6.3. Contact pressure reinforcement due to combustion pressure). Conversely, the ring height clearance must not be too large, as the ring will then exhibit reduced axial guidance. This increases the tendency to ring flutter (Chapter 2.6.7 Ring flutter) and even to excessive twisting, which causes inappropriate wear of the piston ring (excessive convexity of the ring sliding surface) and increased oil consumption (Chapter 1.6.6 Pistonring sealing faces).

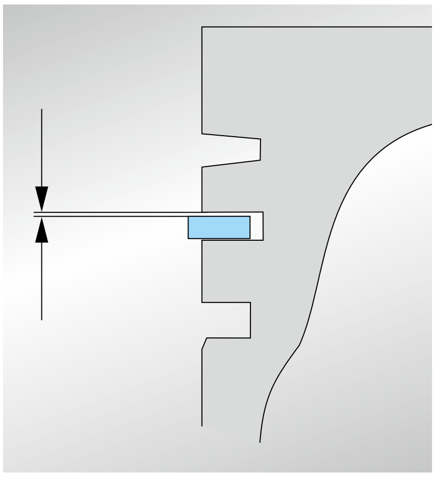


Abb. 1

1.6.9

Ring twisting

Inside steps or inside bevels on piston rings cause twisting in their tensioned (installed) condition. Once they have been disassembled and are untensioned there is no twisting (Fig.2), and the ring lies flat in the ring groove. If the ring has been installed - thus tensioned - it gives way to the weaker side, which is where there is no material due to the inside bevel or inside step. The ring becomes twisted. Depending on the position of the bevel or the step on the lower or upper edge, this is referred to as a positively or negatively twisting piston ring (Fig. 3 and 4).

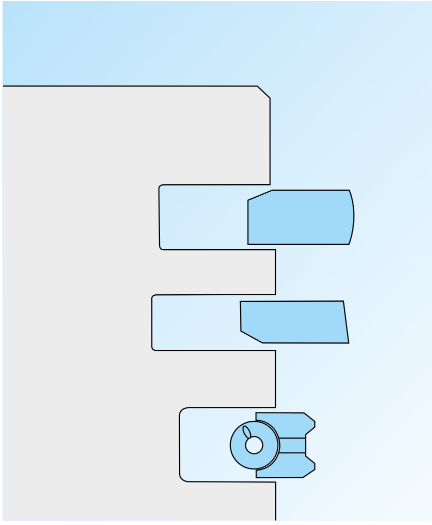


Fig. 2 - Untensioned rings Twisting without effect

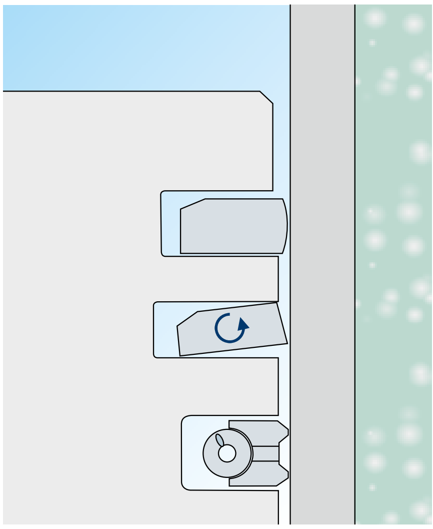


Fig. 3 - Positive twist

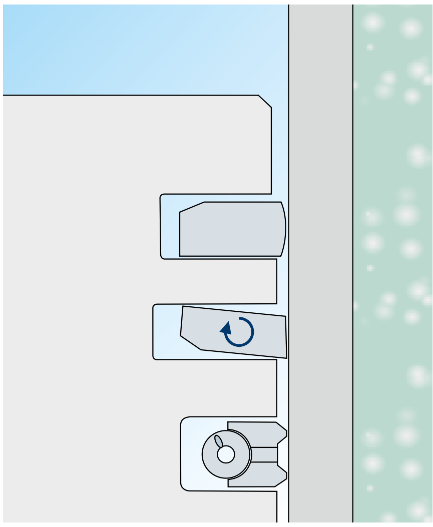


Fig. 4 - Negative twist

Ring twisting under operating conditions
On positive and negative twisting rings, twisting is effective as long as there is no combustion pressure acting on the ring (Fig. 5). Once the combustion pressure has reached the ring groove, the piston ring is pressed flat onto the lower groove side causing an improved oil consumption control (Fig. 6).

Positively twisting rectangular and taper faced rings present efficient oil scraping behaviour. However, in the event of friction on the cylinder wall occurring during the downstroke of the piston, the ring may lift slightly off the lower groove side, allowing the oil to enter the sealing gap and thus contributing to oil consumption.
The negatively twisting ring seals the ring groove at the outer lower ring flank and at the inner upper flank thus obstruc ting the entrance of oil into the groove. For this reason, oil consumption can be positively influenced using negative twisting rings, in particular at part-load operation and vacuum in the combustion chamber (overrun condition).
On negatively twisting taper faced rings, the angle on the sliding surface is approx. 2 ° bigger than on normal taper faced rings. This is required because the angle is partly compensated by the negative twisting.

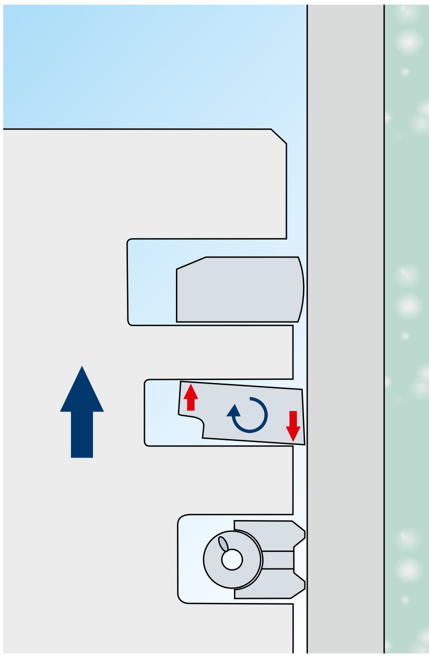


Fig. 5

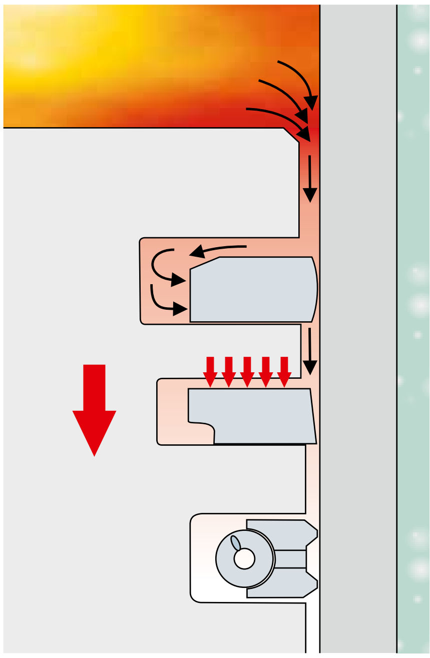


Fig. 6

1.6.10

Form matching capability

By form matching capability we understand how well the ring can adopt the shape of a cylinder wall to achieve an efficient sealing effect. The form matching capability of a ring depends on the elasticity of the ring or the ring body (two-piece oil control rings) or the steel rails (multi-piece oil control rings) and on the contact pressure of the ring/ring body against the cylinder wall. In the process, the form matching capability is the better the more elastic the ring/ring body is and the higher the contact pressure. Large ring heights and big ring cross sections present a high stiffness and, due to their higher weight, cause higher inertia forces during operation. As regards the form matching capability, they do worse than rings with low ring heights and small ring cross sections and consequently lower inertia forces.

Excellent form matching capabilities can be found on multi-piece oil control rings since these have an extremely flexible ring body or steel rails without need to comply with the requirement for high tension. As described in this brochure, on multi-piece oil control rings the pressure force is applied by the associated expander spring. The ring body or even the steel rail is extremely flexible and adaptable.

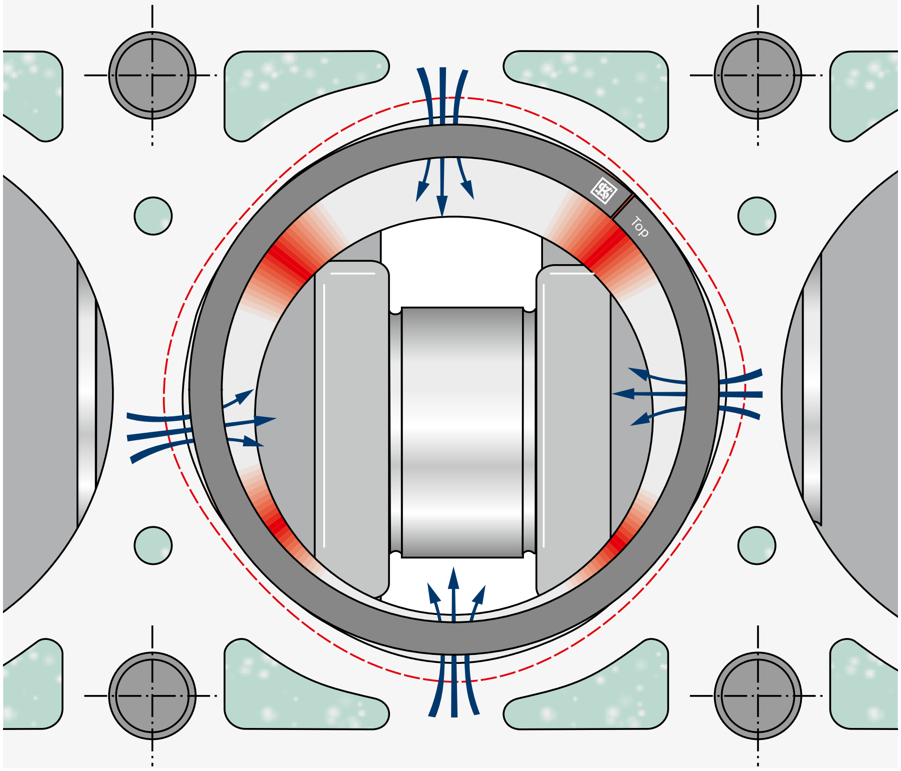


Fig. 1

An efficient form matching capability is of particular importance if shape devia tions cause cylinder ovalities and unevenness which are a result of both distortions (thermal and mechanical) and of machining and fitting errors. See also Chapter 2.3.5 Cylinder bore geometry and roundness.

1.6.11

Piston ring movements

Ring rotation

In order for piston rings to run-in and seal properly, they must be able to rotate freely in their grooves. The ring rotation is the result of the honing pattern (cross grinding) on the one hand, and the rocking movement of the piston at the top and bottom dead centre on the other hand. Flatter honing angles cause fewer ring rotations whereas steeper angles result in higher ring revolution rates. The ring rotation also depends on the engine speed. 5 to 15 revolutions per minute are realistic figures to get an idea of the dimension of the ring rotation. On two-stroke engines, the rings are secured against rotation. As a result, both ring rotation and rebounding of the joint ends into the gas channels are prevented. Two-stroke engines are mainly used in motorcycles, gardening machines and the like. The irregular wear of the rings, a possible coking in the ring grooves and a restricted service life due to inhibited ring rotation is tolerated in this regard. In any case, this type of application is dimensioned for a shorter service life of the engine from the outset. The requirements made on a normal four-stroke vehicle engine that is in road use, are higher by far where the mileage is concerned.

The twisting of the ring joints by 120 ° to each other is only intended for facilitating the start of the new engine. After this period, any conceivable position of the piston ring inside the ring groove is possible, provided the rotation is not inhibited by design (two-stroke engines).

Axial movement

Ideally, the rings rest on the lower groove side. This is essential for the sealing function, since the rings not only seal at the piston ring sliding surfaces but also at the lower ring flanks. The lower groove side seals the ring against gas or the passage of oil at the rear of the ring. The sliding surface of the piston ring seals the front end towards the cylinder wall (also see Chapter 1.6.6 Piston ring sealing faces).

Due to the up- and downstroke of the piston and the direction reversal, the rings are also exposed to inertia forces, causing the rings to lift off the lower groove side. An oil film inside the groove diminishes the lifting effect of the piston rings from the lower groove side caused by these centrifugal forces. Difficulties mainly arise if the ring grooves are expanded by wear and there is, excessive ring height clearance as a result. This causes the ring to lift from its contact point on the piston and also ring flutter, mainly starting at the joint ends. This provokes a loss of the sealing capacity of the piston ring and high oil consumption. This occurs mainly during the intake cycle whenever the rings lift off the groove base and oil is taken into the combustion chamber past the rear end of the ring as a result of the piston downstroke and the subsequent vacuum. During the remaining three cycles, the pressure arriving from the combustion chamber presses the rings onto the lower flank.

Radial movement

The rings do not in fact reciprocate radially, but rather the piston changes from one cylinder wall to the other as a result of the reversal being performed inside the cylinder bore. This occurs both in the upper and lower piston dead centre. The rings are thus moved radially inside the piston ring groove. This results in an oil carbon layer grating as it forms (particularly for keystone rings), and in a connection to the compound rest for ring rotation.

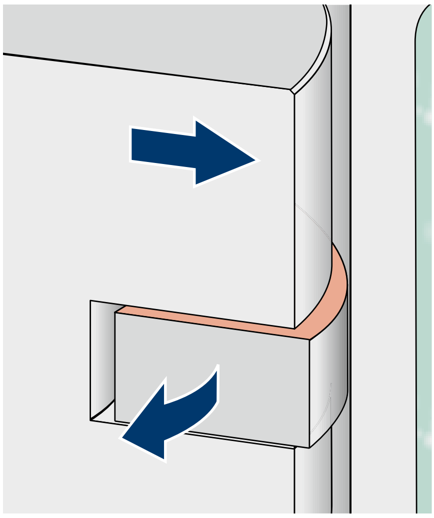


Fig. 1

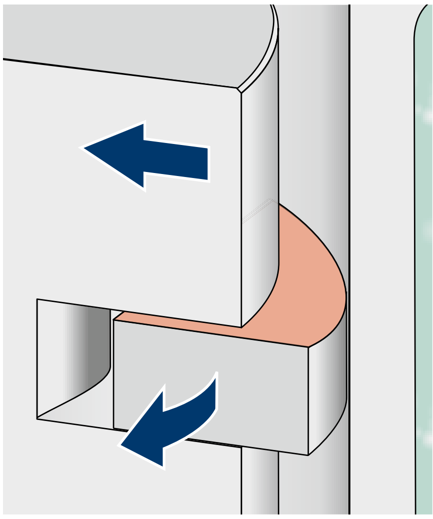


Fig. 2

Ring twisting

As can be seen on the picture, inertia forces, ring twisting and ring height clearance put the rings into motion. As described in Chapter 1.5.6 Ballshaped sliding surface shapes, the piston rings will adopt a ball-shaped shape after a while if they are not already produced with a ball-shape.

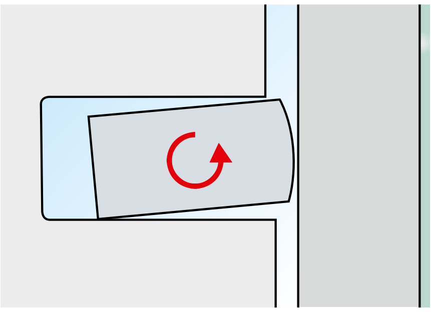


Fig. 3

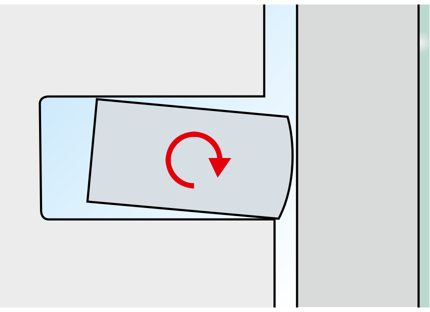


Fig. 4

2.1

Assessment of used components

As an integral part of a sealing system consisting of pistons, cylinder bore, engine oil and piston rings, the piston rings can only perform their task to the extent permitted by the functions of the other components. If the efficiency of one sealing component is reduced, for instance by wear, the overall efficiency of the sealing system will be lowered as a result.

The re-use of already run interacting sliding parts of piston rings (pistons and cylinder bore) should be done using common sense and expertise. The sealing system is only as effective as it's weakest component. It is not practical or even sensible, to attempt to recondition an engine by only changing the piston rings. If the rings are worn, one can also assume that the interacting sliding parts of the piston ring are also worn. Simply replacing the rings while reusing a worn piston or a worn cylinder liner will not yield the desired results. Remedying drops in power or excessively high oil consumption is therefore a pretty hopeless venture and will, if anything, bring only temporary success. The causes on which this circumstance is based are described, among others, in Chapter 1.6.6 Piston ring sealing faces.

Fig. 5

Fig. 6

2.2 | Assessment of used pistons

2.2.1

Measurement and assessment of ring grooves

Whenever new piston rings are to be fitted on used pistons, the ring height clearance will decide on whether the piston can be reused. The piston ring concerned is inserted into the cleaned ring groove and measured with a feeler gauge, as shown in Figure 6 (Page 39). If a new piston ring is to be measured in a used piston, it is better to use the method shown than to fit the piston ring onto the piston. Repeatedly fitting and removing the piston ring on and off the piston may cause a material deformation of the piston ring and affect its functions.

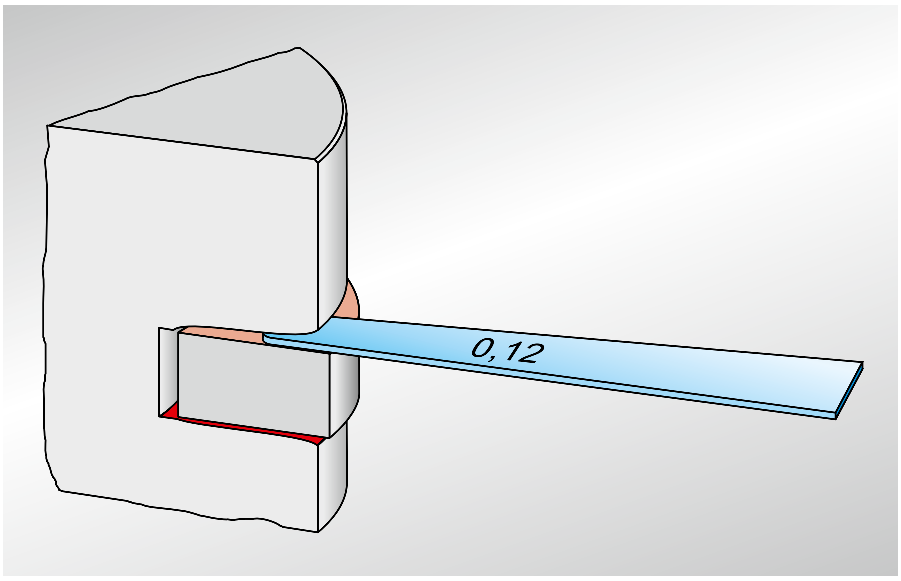
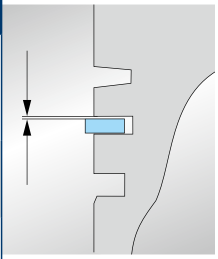


Fig. 1

Ring height clearance (mm)	Usability of the piston		
0.05-0.10	✓	Piston can be reused without any problem.	
0.11-0.12	⚠	Caution is strongly advised.	
› 0.12	✗	The piston is worn and must be replaced.	

Attention

The wear dimension refers to the outer edge of the ring groove to be measured, i.e. it must be impossible to insert the feeler gauge with a thickness of 0.12 mm between piston ring and ring groove, as shown in Figure 2. Otherwise the ring groove is regarded as already worn.

It is not possible to examine the ring height clearance of keystone rings when they are in their fitted and untensioned condition. Due to the keystone shape, the correct ring height clearance in the keystone groove is only achieved after the piston ring has been compressed to the cylinder size or mounted into the cylinder bore. As a result, measurement is almost impossible.

For this reason, the inspection must be limited to visually inspecting the groove for wear (Fig. 2).

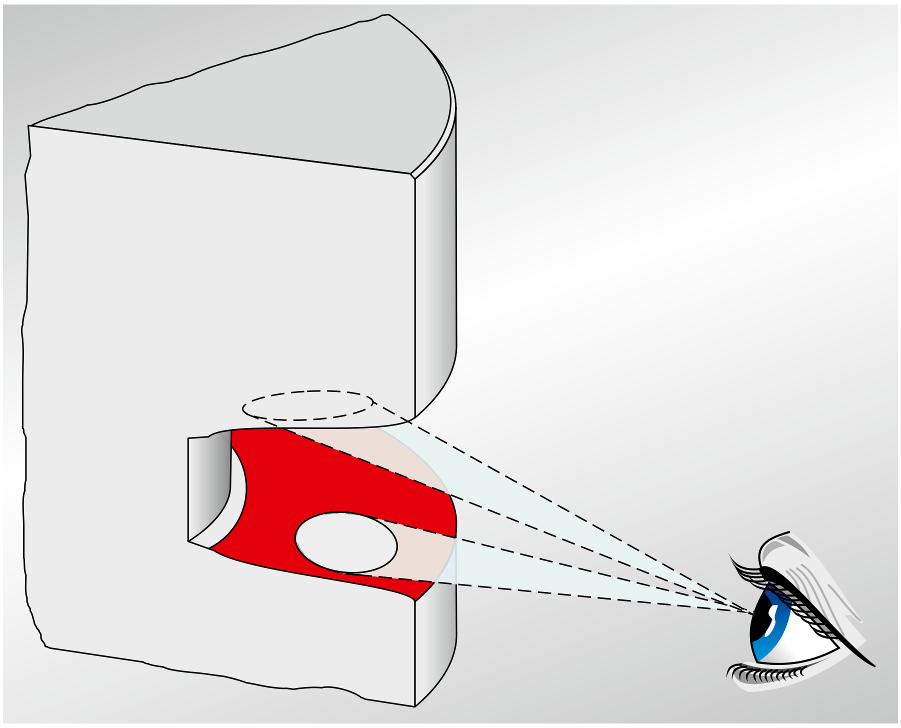


Fig. 2

Test method during production

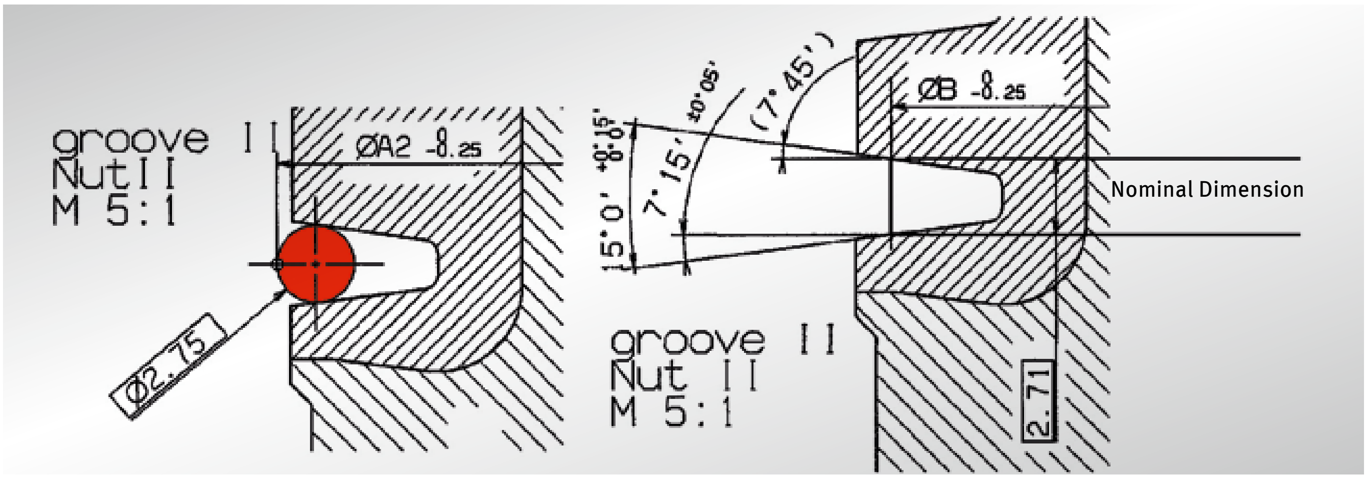


Fig. 3

2.3.1

High-polished running surfaces of the cylinder liner (grey cast iron cylinder)

Bright, mirror-finish cylinder surfaces without any more honing grooves are either the result of natural wear after a long running time, or caused by dirt and mixed friction after a short running time.

The fact that all honing grooves have been removed due to wear is a sure indication that a cylinder bore is worn. Remeasuring using appropriate measuring equipment is no longer necessary. In any event, such cylinder bores should be replaced (cylinder liners) or newly bored and honed (engine blocks).

Locally restricted bright spots on the cylinder sliding surface after a comparably short running time (the honing pattern in this area is also completely removed) are evidence that the area where the bright spot has been formed has been exposed to mixed friction, resulting in increased wear on the cylinder wall. Such locally restricted bright spots are mainly caused by two factors.

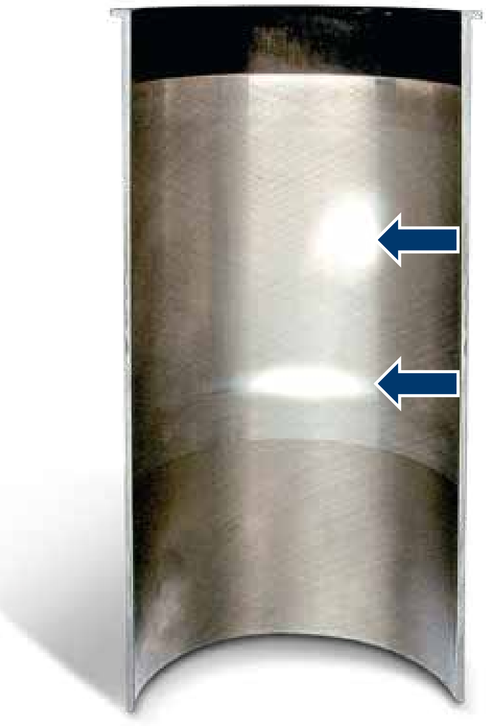


Fig. 1

2.3.2

Locally restricted bright spots due to cylinder distortions

Cylinder distortions cause out-ofroundness at certain point inside the cylinder bore (Fig. 1). The position of the bright spot is identical with the point of origin of the distortion. The piston rings pass these constrictions and remove material there. Insufficient lubrication and mixed friction are caused by the constriction whenever the piston ring slides over the raised spot and consequently touches the cylinder wall.

Causes:

- Thermal distortion due to local overheating which is caused by poor heat transfer (contamination) to the cooling agent.
- Non-observance of specified tightening torques, using wrong O-rings or other distortions as a result of tightening.

Remedies:

- Thorough cleaning and, if necessary, refinishing of the cylinder counterbore of wet and dry cylinder bores.
- Exact compliance with tightening specifications when installing the cylinder head.
- Regular cleaning of the cooling fins on air-cooled finned cylinders
- Ensuring the specified function of the cooling system (circulation speed, cleanness).
- Using the prescribed sealing rings (dimensions, material composition).

2.3.3

Bright and polished spots on the upper cylinder section (Bore Polishing)

There are bright spots in upper section of the running surface of the cylinder liner (Fig. 2) travelled over by the piston top land. These spots are caused by hard deposits on the top land due to irregular combustion, poor oil quality or low combustion temperatures, caused by frequent idling periods or part-load operation. The carbon layer (Fig. 3) results in abrasive wear on the cylinder wall, an interrupted oil film, mixed friction, increased piston ring wear and consequently in high oil consumption.

Remedies:

- Proper engine operation.
- Using the specified oil qualities.
- Using branded fuels.
- Proper maintenance, inspection and adjustment of fuel injection system.

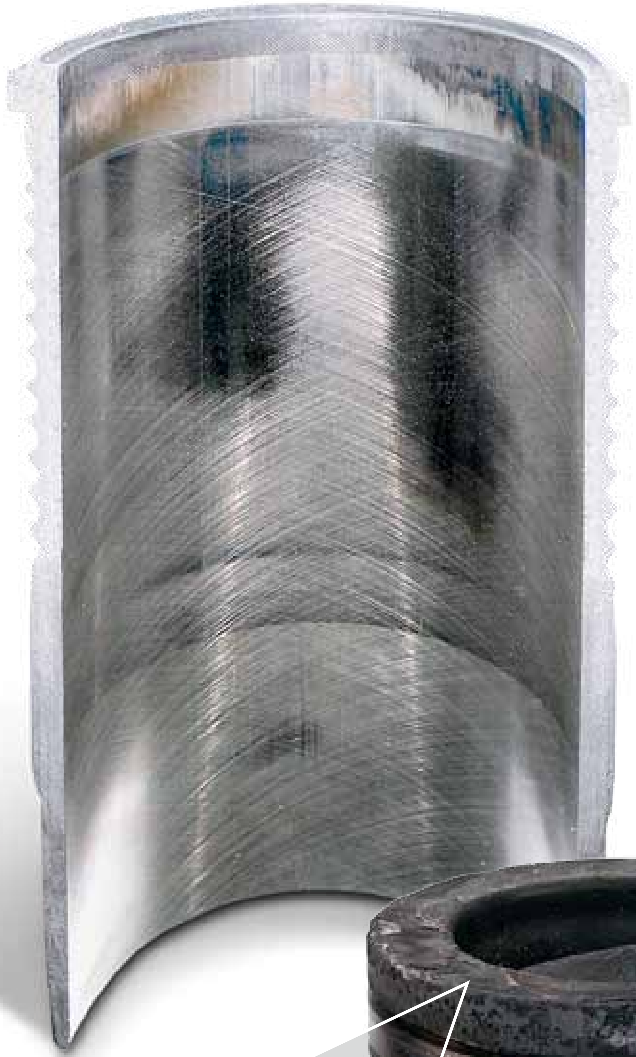


Fig. 2

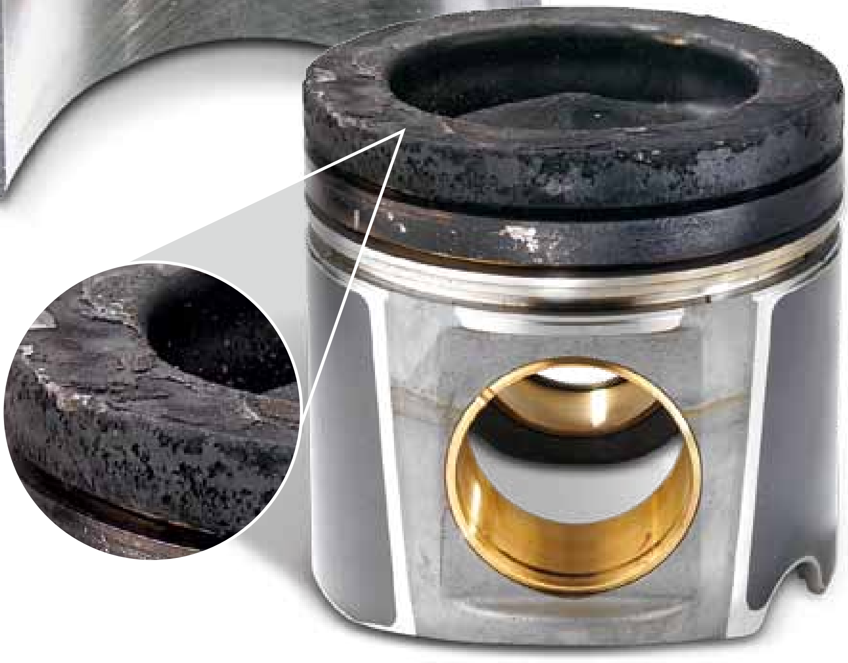


Fig. 3

2.3.4

Top ring reversal bore wear

Top ring reversal bore wear (Fig. 1) appears at the reversal points of the piston rings at the top and bottom dead centre after a longer runtime. The piston speed is reduced in this section, and even stops briefly at the reversal point. This reduces the lubricating effect, since the piston ring is no longer floating on the oil film due to the lack of relative speed to the cylinder wall and comes into metal contact with the cylinder wall. The example of a water skier makes this clearer. As soon as the speed of the boat is inade quate the water skier sinks into the water.

Due to design, wear on the top ring reversal bore is most pronounced in the piston ring reversal section close to the top piston dead centre, because the cylinder surface is exposed to hot combustion at that point which affects lubrication.

The extent of top ring reversal bore wear is decisive on whether the cylinder liner or the engine block may be reused or not. If the top ring reversal bore wear exceeds the values specified in the chart, the cylinder liner must be replaced or the engine block rehoned. If the cylinder bore is worn to a similar extent in another section, the wear dimensions specified below are also applicable.

Engine design	Top ring reversal bore wear limit "X"
Petrol engines	≥ 0.1 mm
Diesel engines	≥ 0.15 mm

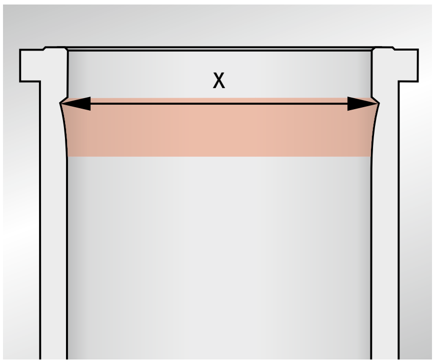


Fig. 1

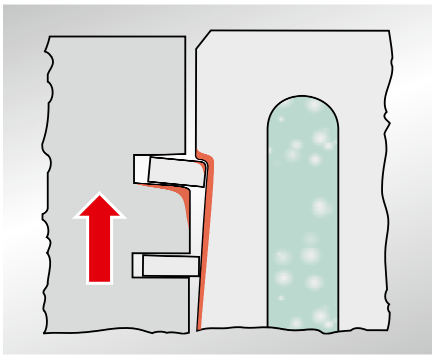


Fig. 2

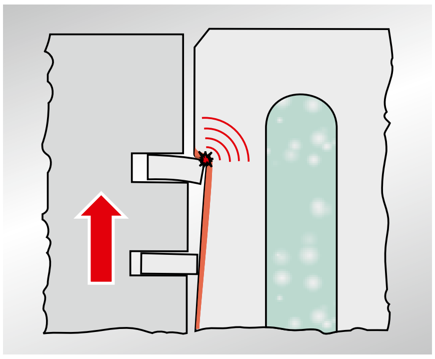


Fig. 3

Figures 2 and 3 show what happens when a new piston is installed into a worn cylinder bore. Since the new piston has no ring groove wear at all and piston rings still have sharp edges, the piston ring edge hits against the wearing edge of the cylinder. High mechanical forces, excessive wear, piston ring flutter and high oil consumption are the consequence.

2.3.5

Cylinder geometry and roundness

Perfect cylinder geometries are the prerequisite for optimal piston ring sealing. Deviations from the cylinder shape, out-of-roundness, dimensional faults and distortions in the cylinder bores result in sealing problems at the piston ring and in an increased passage of oil into the cylinder, increased blow-by gas emission, temperature and efficiency problems, premature wear and - not least - in piston damage.

Classification of out-of-roundness on cylinders

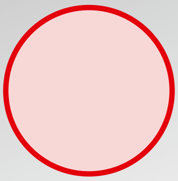


Fig. 4

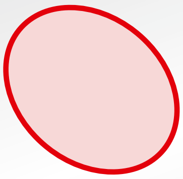


Fig. 5

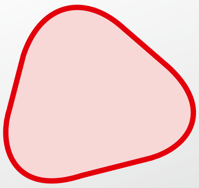


Fig. 6

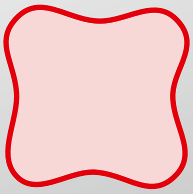


Fig. 7

Out-of-roundness in the bore geometry is subdivided into different orders. A perfect cylinder bore without any out-of-roundness or form deviations in axial direction is a so-called first order bore (Fig. 4). Oval bores frequently due to the machining faults or poor heat dissipation, are called out-of-roundness of second order (Fig. 5). Triangular third order out-of-roundness (Fig. 6) mostly results from a superposition of second and fourth order distortions. Fourth order out-of-roundness (Fig. 7), thus square imperfect shapes, are usually caused by distortions arising from tightening the cylinder head bolts.

The size of the out-of-roundness can be between zero and several hundredth of a millimetre. Due to small piston fitting or piston running clearances, as exist in various engines, distortions of more than a hundredth millimetre (0.01 mm) may consequently already cause problems. Piston rings can only reliably seal small second order out-of-roundness , i.e. slightly oval cylinder bores and minor keystone shapes in axial direction. Third and fourth order out-of-roundness, as frequently caused by distortions due to tightening and/or machining faults, rapidly make piston rings reach the limits of their sealing function. In particular on more recent piston designs with piston ring heights close to one millimetre or even less, sealing is becoming increasingly problematic. The constructional reduction of piston ring heights is intended for decreasing frictional losses in the engine and thus reducing the fuel consumption. Since the contact areas to the cylinder wall of such rings are smaller, it is essential that the piston ring tension is reduced as well. Otherwise, the specific surface pressure of the ring would become too great and the tribological properties would deteriorate. However, if the bore geometries are correct, this constructional reduction of the piston ring tension has no negative effect. The rings seal very well, cause only minor frictional losses and have a long service life. But on out-of-round distorted cylinders, the rings cannot or only very slowly adapt to the cylinder wall as a result of the low piston ring tension, and consequently, cannot fulfill their proper sealing function.

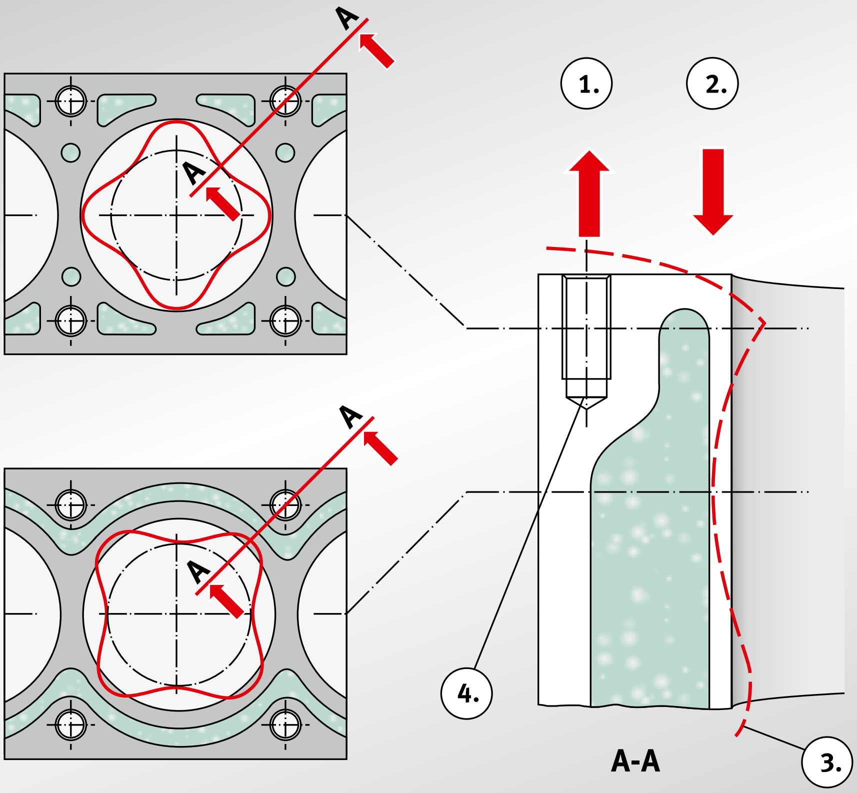
2.3.6

Causes of out-of-roundness and distortions on cylinder bores

Out-of-roundness and distortions in cylinder bores may be caused by the following:

- Thermal distortions caused by poor heat dissipation as a result of faults in the coolant circulation or due to clogged, oily cooling fins and/or ventilation problems on air-cooled engines. Local overheating on the cylinder sliding surface leads to increased thermal expansion in this area consequently causing deviations from the ideal cylinder shape.
- Constructional thermal distortions resulting from varying thermal expansion during engine operation.
- Thermal distortions resulting from poor lubrication and cooling during cylinder machining.
- Out-of-roundness caused by excessive machining pressures or by using wrong honing tools.
- Distortion due to tightening on cylinder bores due to inaccuracies in shape and incorrect screw tightening.

The figure shows a fourth order cylinder distortion which frequently results due to the design when the cylinder head bolts are (even properly) tightened.



1. Bolt force of cylinder head bolts
2. Pressure force of cylinder head and cylinder head gasket
3. Cylinder bore deformation (overexaggerated representation)

Fig. 1

2.3.7

Refinishing used cylinder bores

When pistons or piston rings are replaced, so-called hone brushes or spring-loaded honing stones (Fig. 2 and 3) are used in practice. However, this has actually very little to do with honing. The more or less worn running surface of the cylinder liner is only cleaned and slightly roughened during this process, which does not bring about any improvement of the cylinder geometry. Since the grinding tools are spring-loaded, they follow every out-of-roundness and distortion exactly without improving the cylinder geometry. As a result of the low contact pressure, it is not possible to achieve any meaningful roughness which could contribute to improving lubricating effects. The frictional resistance for the new piston rings is slightly increased so that they can adapt more quickly to the cylinder wall. But the wear on the cylinder surface cannot be either undone or improved. If the piston rings are worn, experience shows that the cylinder wall is worn to the same extent. The improved appearance of the cylinder bore should not hide the fact that it is more like “cosmetic operation” than an expedient reconditioning or repair method.

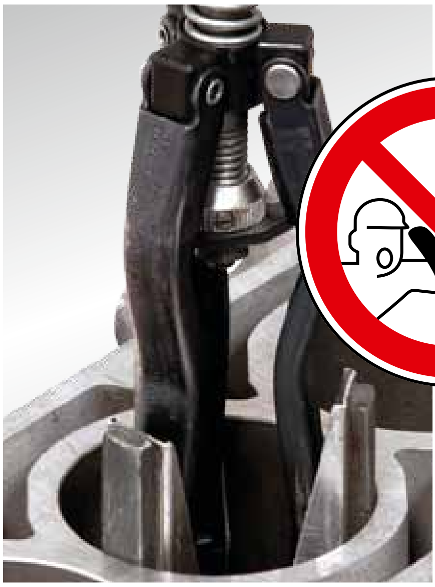


Fig. 2

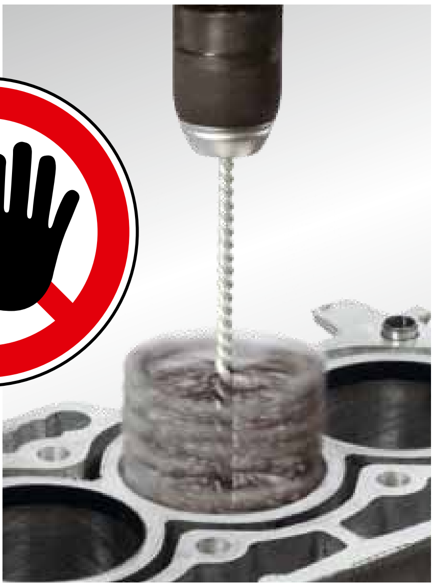
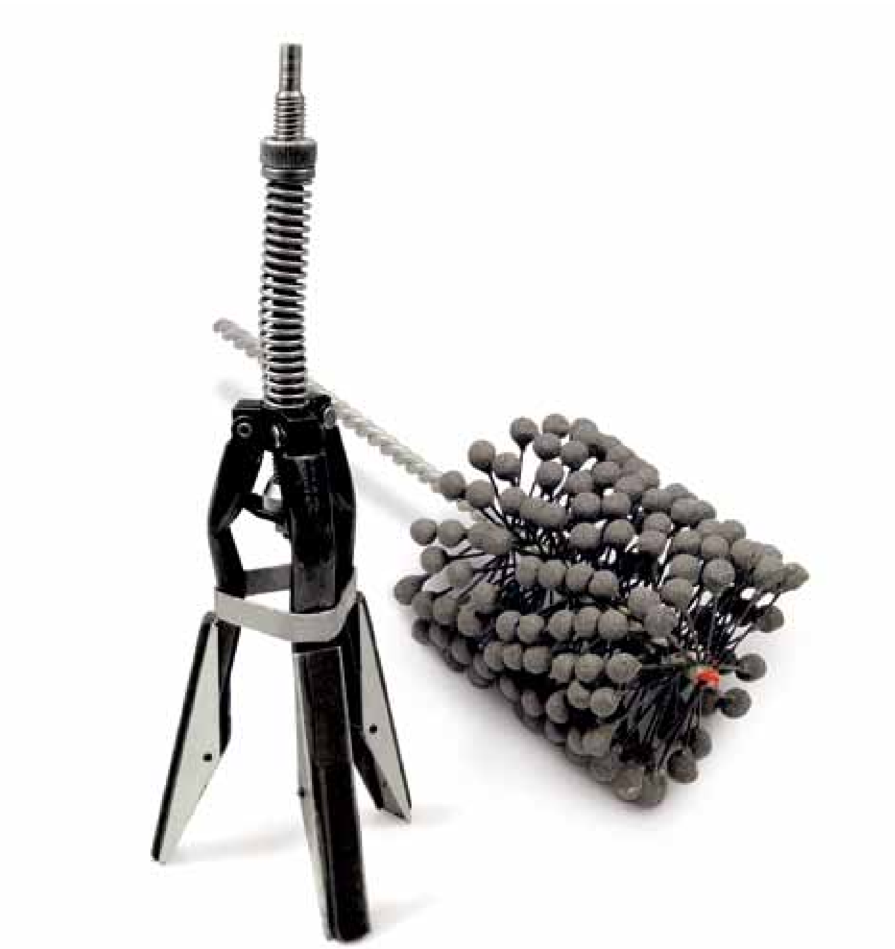


Fig. 3



The most severe piston ring problems and damage arise when the rings are not properly fitted onto the piston. In this process, the piston ring experiences the greatest mechanical strain. The contour and radial pressure distribution achieved during production suffers due to improper fitment onto the piston to such an extent that the required sealing function is frequently achieved only fractionally or not at all.

A piston ring should only be expanded until the inside diameter can be slipped over the outer diameter of the piston. Any further expansion will result in ring distortion, in particular at the back (Fig. 1), causing considerable sealing problems in its installed condition.

Fractures, coating separation (in particular on molybdenum-filled rings), reduced pressure forces at the back of the ring up to generated crescent-shaped gaps (Fig. 2) impair the proper functioning of the ring or make it fail completely.

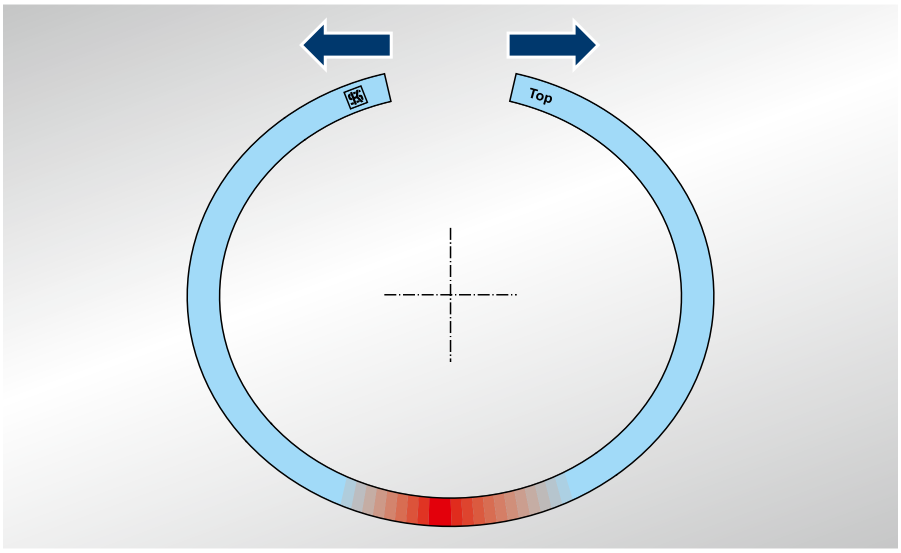


Fig. 1

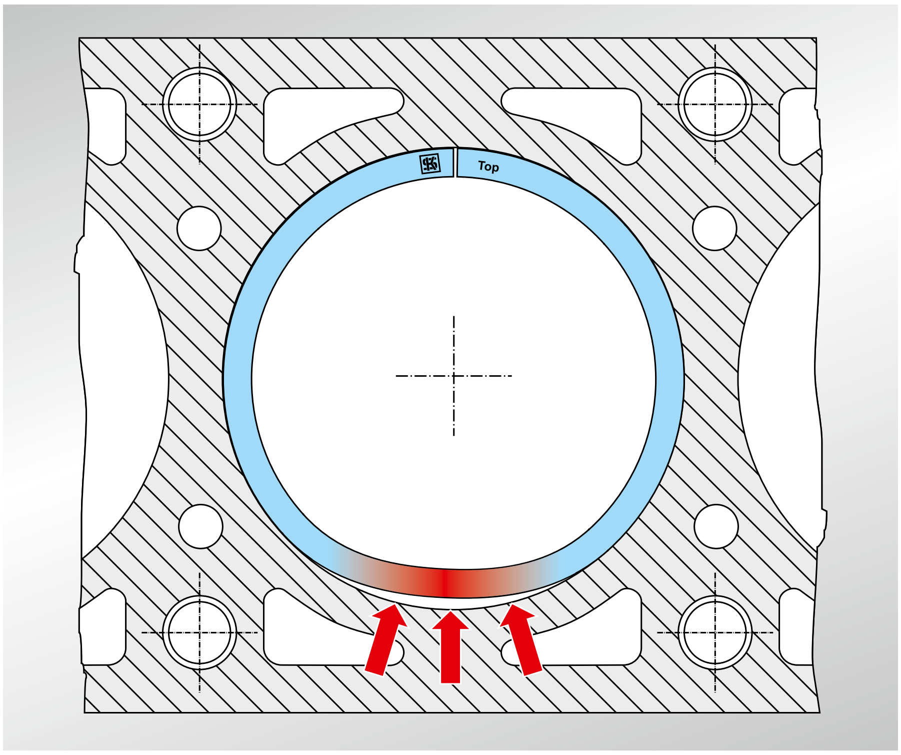


Fig. 2

Attention

Never bend up piston rings to increase their tension! If the joint ends are pulled apart, the ring will only bend at one point - at the back. The ring tension cannot be increased in this way. Far from it. If the ring is excessively bent or deformed, it loses its round shape and will never be able to seal properly.

2.4.1

Fitting and removing piston rings

- Clean used pistons thoroughly from adhering dirt. Make sure that the ring grooves are free of carbon and dirt. Use a drill or another suitable tool to clean the oil draining bores, if necessary.
- Pay attention that no damage is caused to the groove sides when removing the carbon. The lower groove side is a sealing face. Damage due to scratches may cause high oil consumption or an increased blow-by gas emission during engine operation.
- It is essential that piston ring pliers are used for fitting and removing piston rings. Other devices, such as a wire loop or screwdriver, damage the piston ring as well as the piston.
- Never fit the rings manually (except steel rail oil control rings). There is not only the risk of ring fracture, distortion and overstretching, but also the danger of injury should a ring break or due to sharp ring edges.

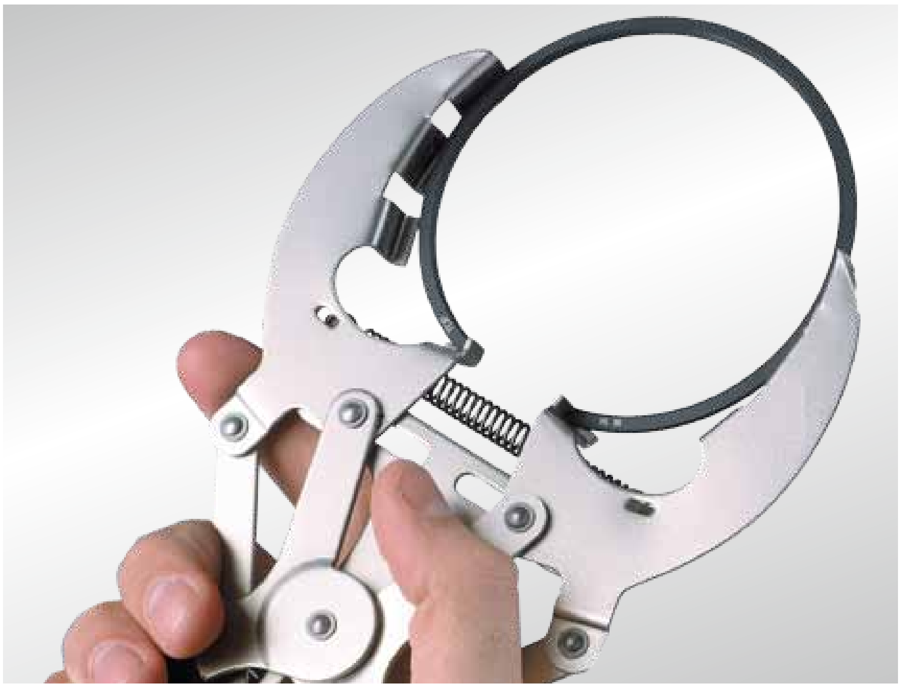


Fig. 3

⚠ **Attention**

If the piston ring is fitted quickly by hand and without breaking, this may be evidence of the skills of the mechanic, but it will usually result in damage to the piston rings when they are fitted.

Piston Ring Service Tool Set
Article No. 50 009 913

2.4 | Assembly of pistons and piston rings

- Never fit a ring onto the piston as shown (Fig. 1). If the ring is deformed and no longer lies flat in the groove, it can no longer rotate in it, wears on one side or will no longer seal properly. Even worse is, however, the peeling or partial fracture of the molybdenum coating of a ring. If the loss of the sliding layer does not already occur during installation, it will appear at the latest during engine operation. The sliding layer peels off, which results in damage to piston and cylinder surface. The piston seizes in the cylinder bore because hot combustion gases are blown between piston and cylinder wall. The loose parts cause damage to the piston and cylinder sliding surfaces.
- Avoid any unnecessary fitting and removal of the piston rings. The rings will become slightly deformed during each fitment. Do not pull-off rings from already pre-assembled pistons, for instance to remeasure them.
- Stick to the fitting sequence of the rings. First mount the oil control ring, then the second and then the first compression ring.
- Pay attention to the markings. “Top” means that this side must face the top, towards the combustion chamber. If you are not sure or if there is no „Top“ marking, then mount the ring with the inscription facing upward. “Top” does not mean that this is the first compression ring.

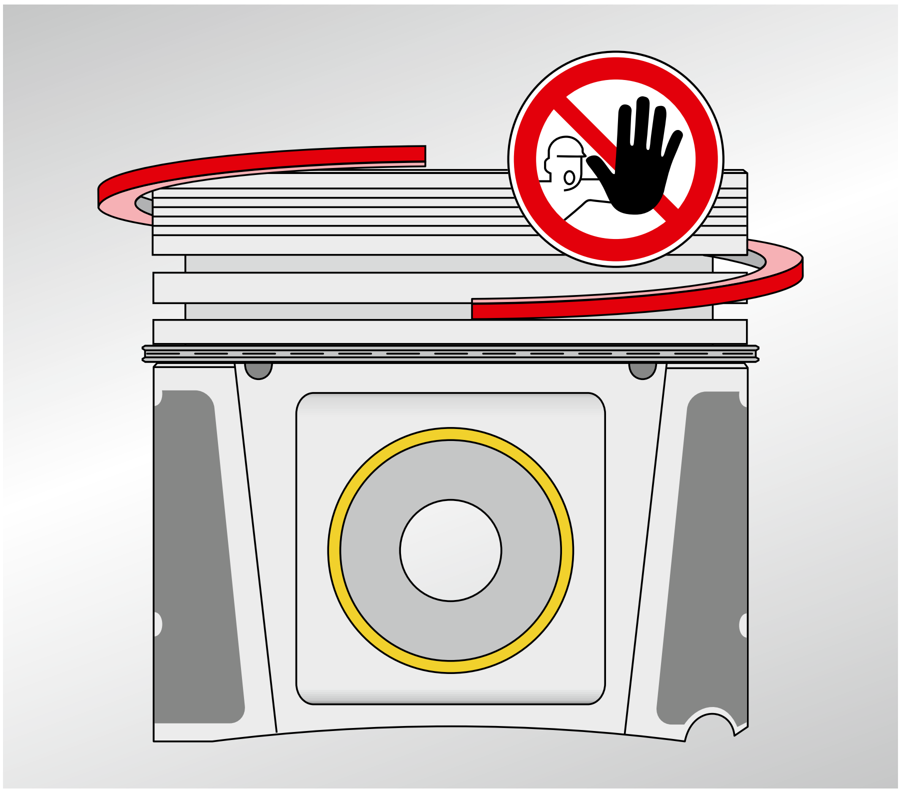


Fig. 1

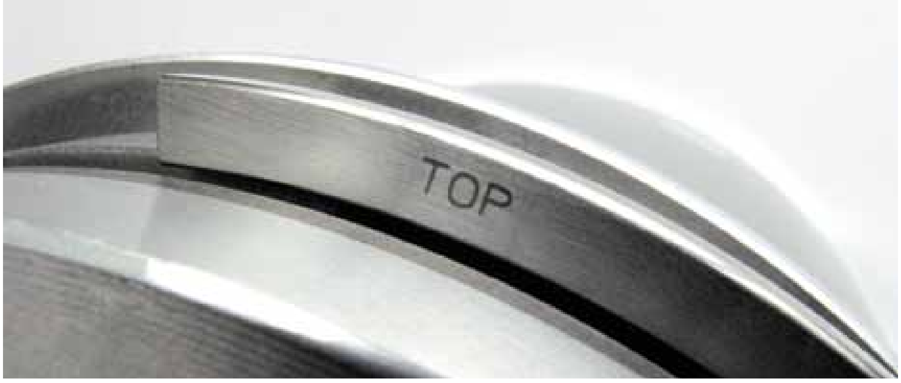


Fig. 2

➔ Check whether the rings can rotate freely in the ring grooves.

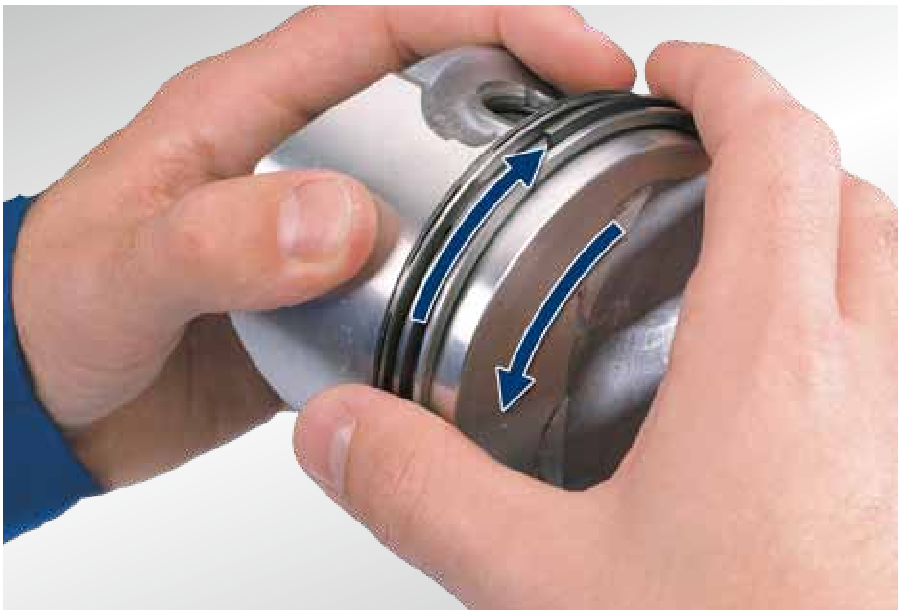


Fig. 3

➔ Check whether the ring disappears completely in the ring groove along its entire circumference, i.e. the sliding surface of the ring should not protrude over the piston skirt. This is essential since the ring function is not warranted if there is no groove base clearance (incorrect ring fitted or groove base carbonised).

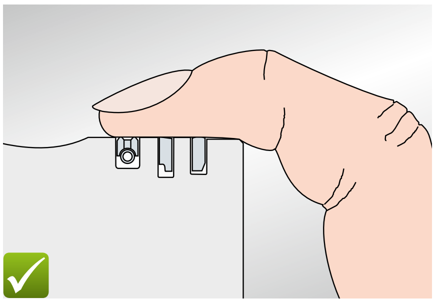


Fig. 4

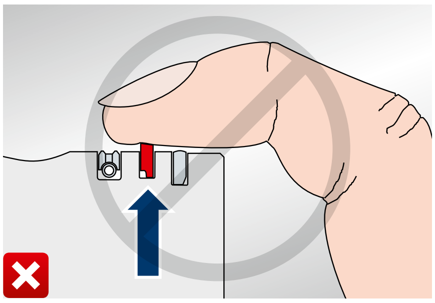


Fig. 5

➔ When mounting two-piece oil control rings, always pay attention to the position of the spiral expander (Fig. 6). The ends of the spiral expander must always be opposite the ring joint.

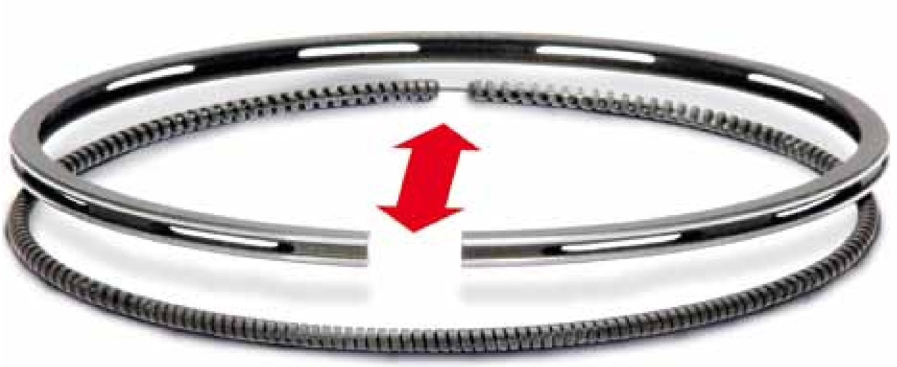


Fig. 6

2.4 | Assembly of pistons and piston rings

- With three-piece rings, the correct position of the expander spring is indispensable for ensuring the oil scraping function (Fig. 1 and 2). Prior to installing the piston, always check the position of the expander springs on pistons with pre-assembled rings. The ends of the springs are in an untensioned condition and may slide over each other. Both colour markings on the expander spring ends must be visible (Fig. 3). If these are not visible, the spring is overlapping and the ring can consequently not function properly. All ring joints of the three-piece oil control ring (the two steel rails and the expander spring) must be mounted with an offset of 120° to their counterparts.

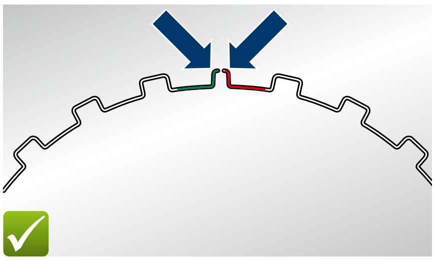


Fig. 1

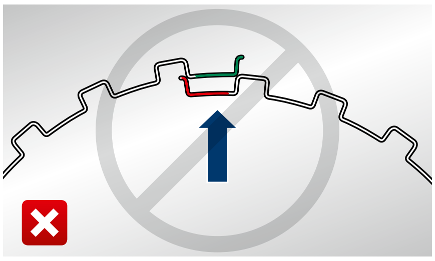


Fig. 2

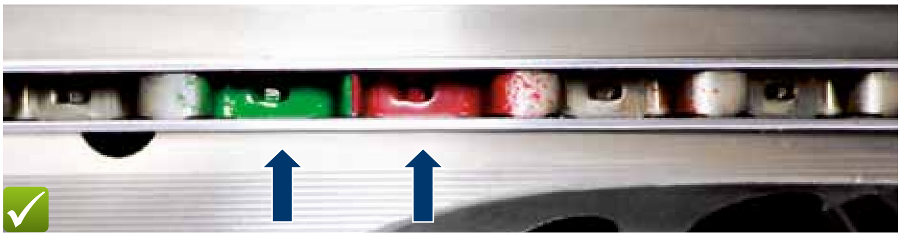


Fig. 3

- Rotate the piston ring joints of the pre-assembled piston in such a way that the ring joints are approx. 120° offset to each other. This helps the pistons and/or the rings during the first engine start. Reason: The compression at the first engine start is slightly lower since the piston rings have not yet been run-in. Offsetting the joint ends prevents too much blow-by gas from being produced during the first start of the engine and the engine starts poorly.

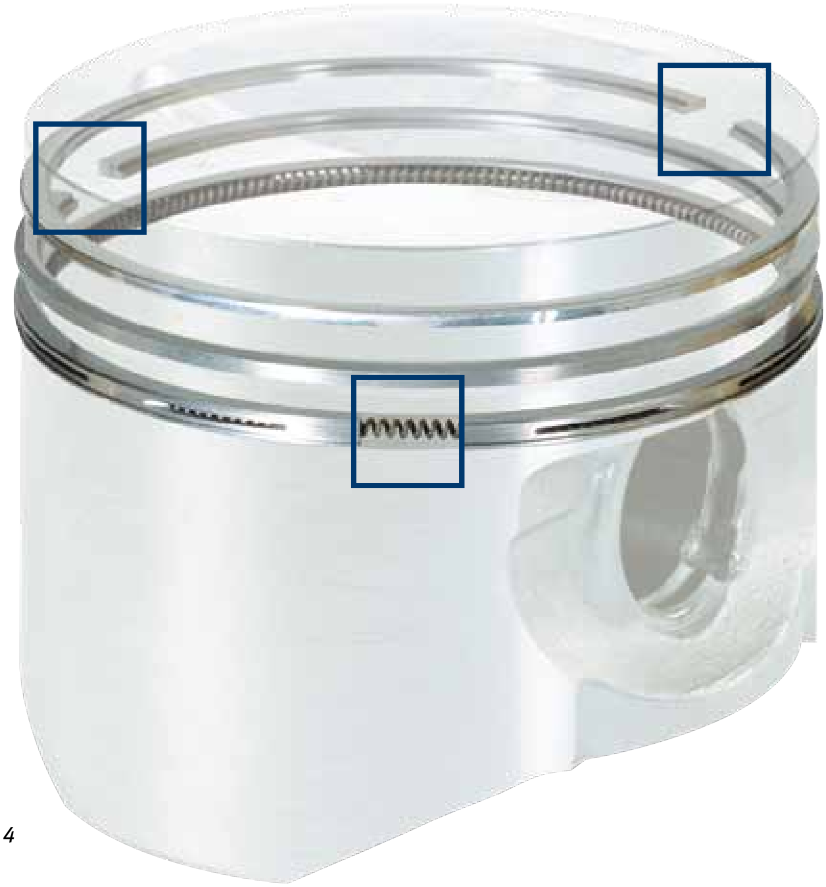


Fig. 4

2.4.2

Fitting the piston into the cylinder bore

- Thoroughly clean the sealing surface of the engine block from sealing residues, if this has not been done during the reconditioning process.
- Thoroughly clean all tap holes from any adhering dirt, oil and coolant.
- Carry out all cleaning work prior to fitting the pistons into the cylinder bores.
- Apply a thin layer of fresh engine oil to all piston surfaces. Do not forget the piston pin and conrod bearings.
- Pay attention to the assembly direction of the piston (markings on the piston crown, valve pockets).
- Clean the cylinder bore again using a cloth moistened with engine oil.
- Check your piston ring scuff band for damage and dents and remedy these or replace the tool if necessary.
- Take care during piston fitting that the scuff band or the conical assembly sleeve are positioned flat on the cylinder head sealing surface.

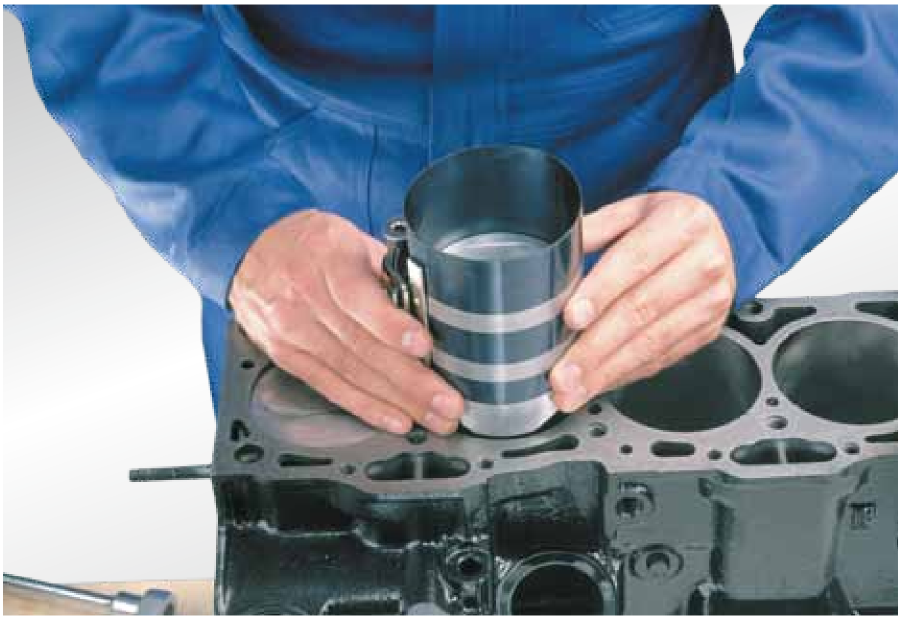


Fig. 5

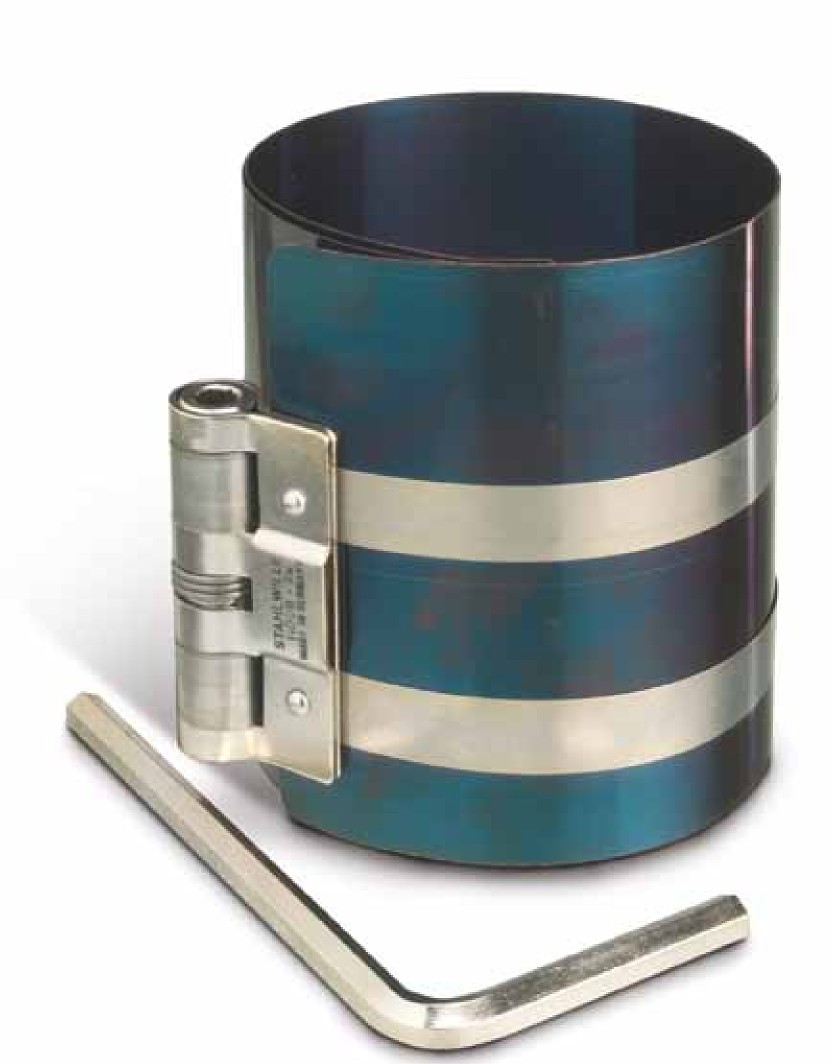


Fig. 6

- Do not use too much force to install the piston. If a piston does not slide smoothly in the cylinder bore it is essential to check the scuff band. The opening of the band in should not necessarily be turned to correspond to the joint ends of the rings.
- Never install the piston in the engine without using a tool (risk of injury, risk of ring fracture).
- If a hammer handle is used for installation, it is essential that only the dead weight of the hammer acts on the piston crown. Never use the hammer to drive the piston forcefully into the cylinder bore. Even if the piston rings do not already break during installation, they may still be deformed and will not fulfil their task properly.
- Forceful installation will not only damage the rings but may also damage the piston. This is particularly the case with pistons in petrol engines. Their top or ring lands can be extremely thin and easily break partially or completely if they are hit. Power loss and early (and costly) repairs will then result.
- Prevent dirt and sand from falling into the cylinder bore after the pistons have been installed. Place or insert clean cloths on/into the bores if necessary to avoid any penetration of dirt. This is in particular recommended for work carried out outdoors or in very dusty environments.

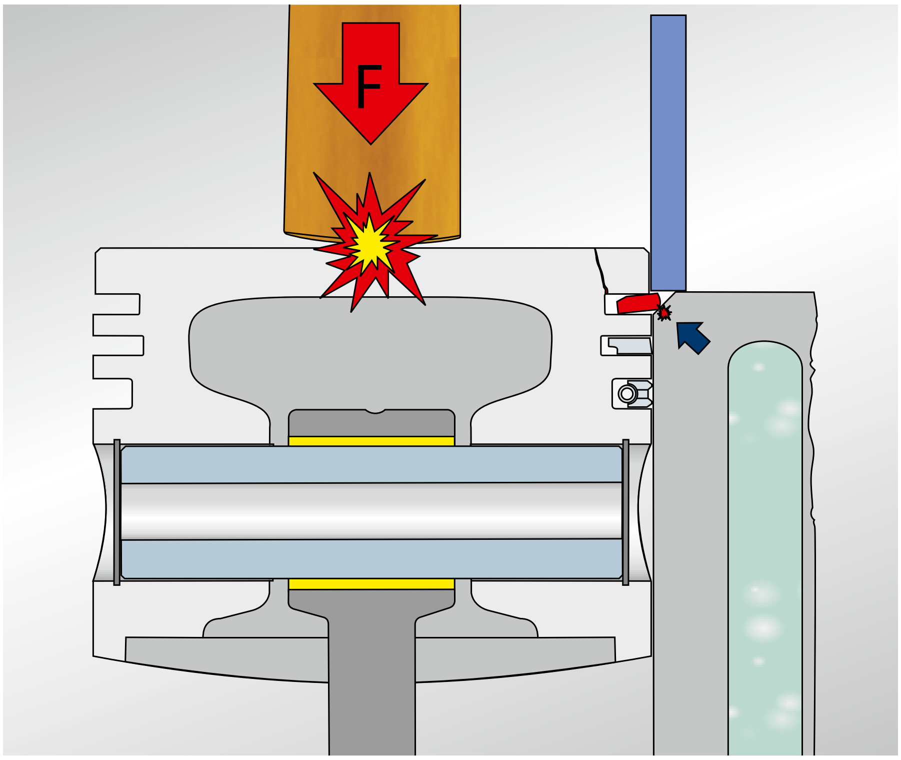


Fig. 1

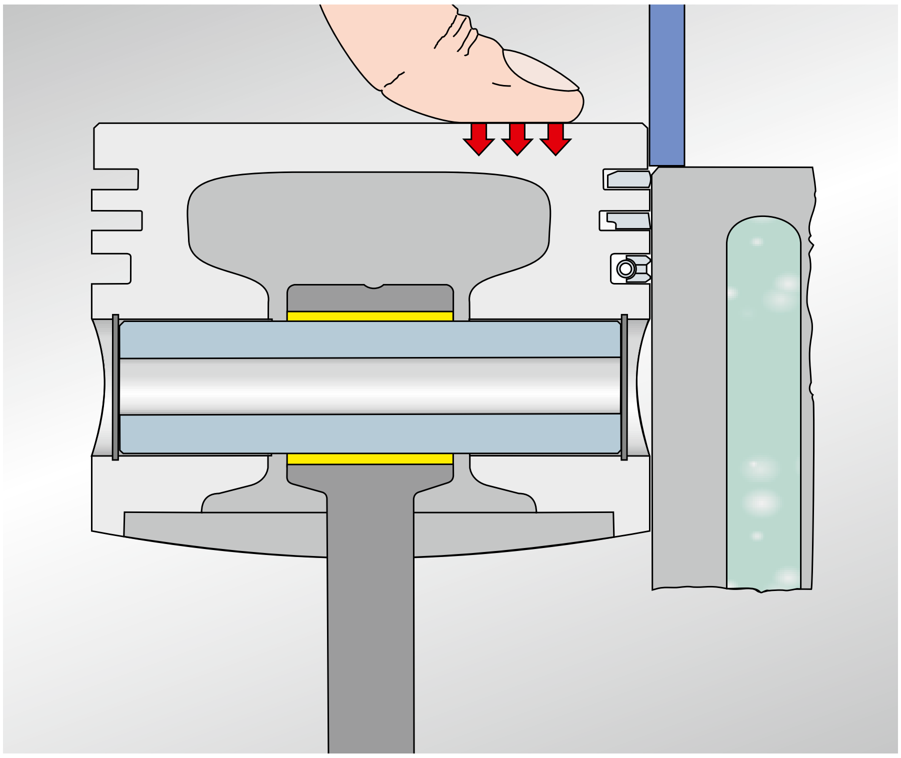


Fig. 2

2.5.1

General

When speaking of running-in engines, one normally thinks of all the moving parts which have to adapt to each other. This is basically correct, but it applies in particular to piston rings. Piston rings are components which as a result of their task, are subjected to the greatest stresses and not only have to adapt to the surface of their associated parts, but must afterwards seal perfectly. Piston rings are thus the components that profit the most from proper and thus efficient running-in. None of components supplied with pressure-oil has to withstand such great strain as piston rings.

There are quite different opinions between customers and technicians as regards the initial starting and running-in of reconditioned engines. There is on the one hand the opinion that a run-in time between 500 and 1500 km is still required, and the second point of view is that the run-in time is not necessary. The latter conclusion is also based, not least, on the statements of some engine manufacturers that do not require any specific engine running-in. Both opinions are correct and justifiable and one ought to just differentiate between brand-new and reconditioned engines.

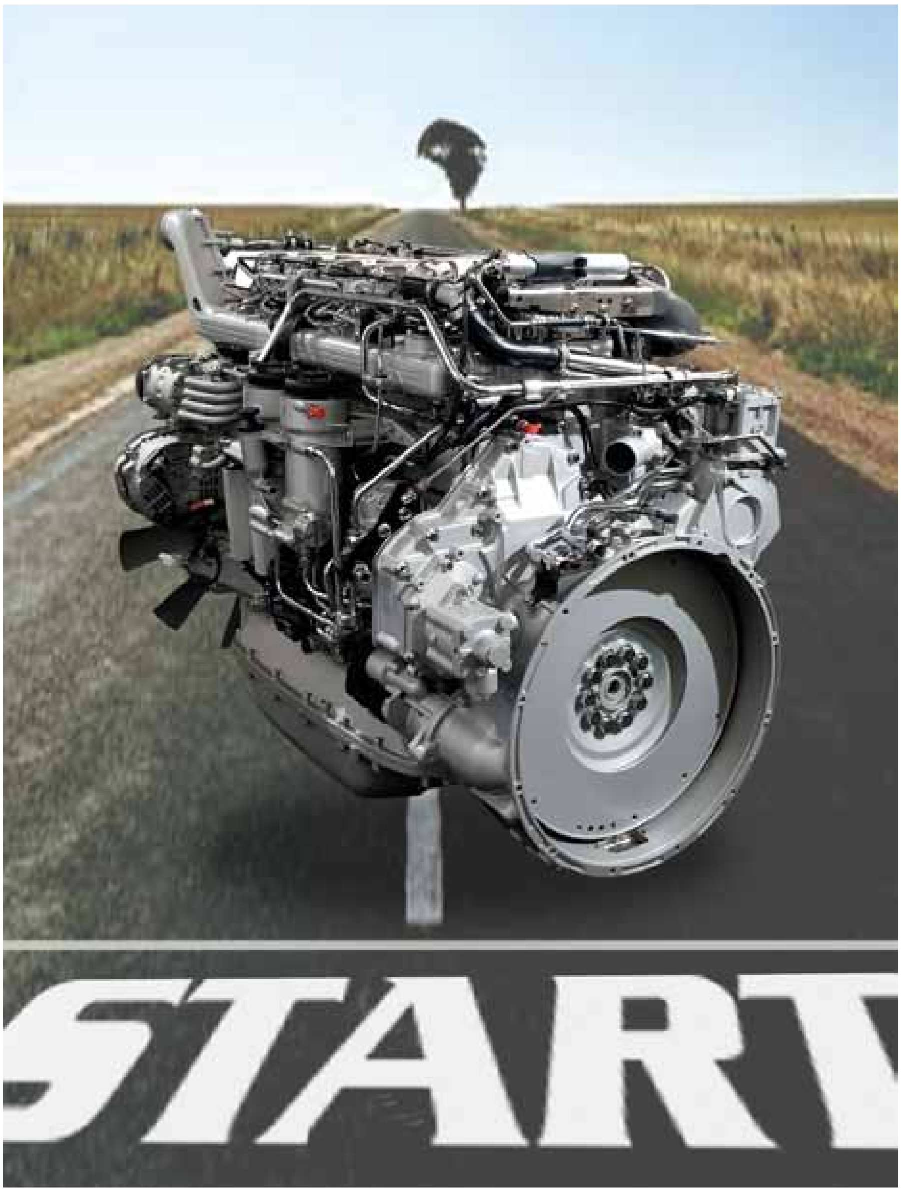


Fig. 3

2.5.2

Running-in brand-new engines

The most modern procedures are implemented nowadays for producing new engines. The interacting sliding parts are produced at such a high rate of precision that the processes that occurred earlier, during the engine's run-in time, are already anticipated during the special manufacturing process for the components. This is accomplished by specific processes (for instance for running surfaces of cylinder liners) as well as by precision-machining processes for the other interacting sliding parts. The processes used are primarily lapping processes to remove from the surfaces superfine burrs and unevennesses that have been generated during the machining processes. In former times, this adaptation was left to the interacting sliding parts which had to adapt to each other during the run-in time. However, this caused considerable material losses. Piston rings, for instance, already lost a considerable part of their wear reserve during the first operating hours. Especially nowadays, when every milligram of exhaust emission is cause for haggling, engines are sought after which keep their defined fuel-consumption figures and, as a result, maintain their pollutant limit values, right from the very start.

An engine run-in during which the sliding surfaces must first adapt to each other by way of friction and above-average wear is hardly conceivable in modern engine manufacture. The end user expects to get a mileage from the engine which is many times greater than anything considered as optimal 25 years ago. A brand-new vehicle is subjected to a coldstart “marathon run” until it has passed the various logistics centres and transports and arrives at the customer. An engine may frequently have to perform up to 150 cold starts without reaching operating temperature between these starts. In this context the shipment to other countries and continents has to be considered. An engine that still had to be run-in would have a very bad start under these circumstances.

Another reason for the relaxed running-in rules for brand-new vehicles is the factor that, due to today‘s traffic density, it is almost impossible to operate the vehicles at their performance limits. Even on motorways without any speed limit, it is hardly possible to reach the top speed or the rated engine power of the vehicle for a longer period. It used to be possible for the driver of a 30 kW vehicle travelling rapidly at a low maximum speed to drive his vehicle for a long time at full load without any difficulty even on a normal country road.

Fig. 1

2.5.3

Running-in reconditioned or repaired engines

In contrast to brand-new engines, it is absolutely essential to run-in reconditioned engines on which new cylinder liners have been used or the cylinder bores have been bored to the next oversize and honed.
In practice, an engine reconditioner (depending on the machinery and equipment available) cannot always work as precisely and so free from contamination as during initial production in the manufacturing plant.

Used engines will not become “as-new” as a result of reconditioning. Frequently, new and used parts are combined and, to save costs, engines are not consistently and completely overhauled. Running-in is most necessary whenever cylinder bores, cylinder heads or crankshafts have been refaced. In practice, it is not always possible to achieve the same machining parameters as during initial production, since the values are unknown or the available machines only allow for standard machining processes. For these reasons, it is recommended that the following instructions for running-in reconditioned engines are observed.

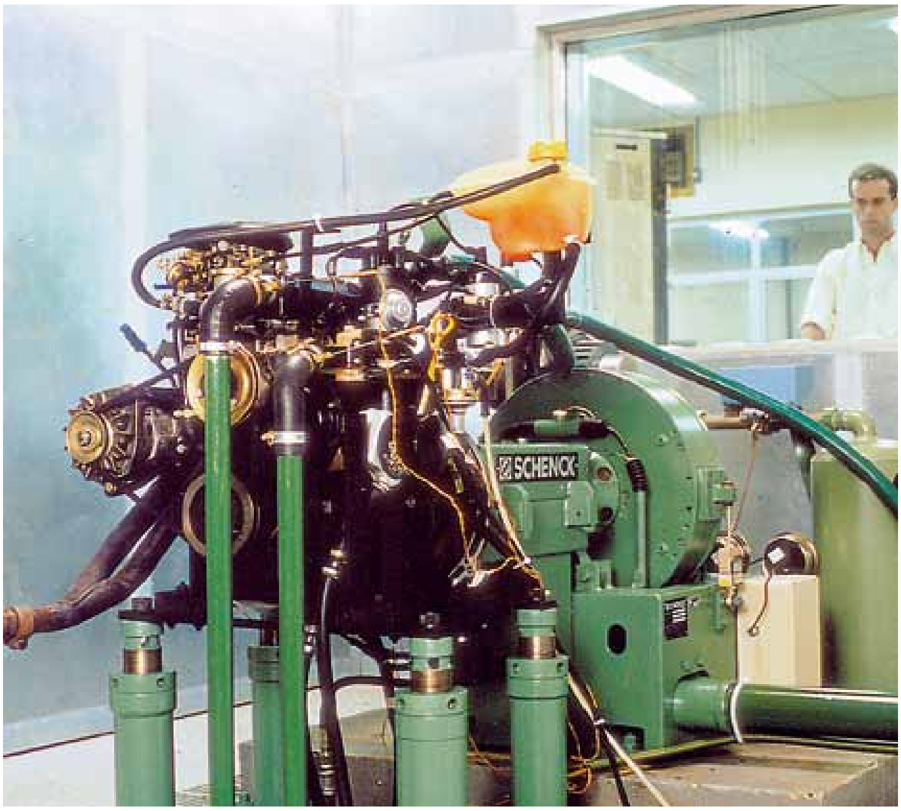


Fig. 2

2.5.4

Running-in instructions for reconditioned engines

- Always run-in the engine on the road or an engine test rig.
- Do not fully load the vehicle.
- Operate the engine up to max. 2/3 of its maximum speed and changing the engine speed at intervals.
- When driving, shift gears up rapidly, avoid low-speed driving conditions, and do not run the gears up to the limit.
- No prolonged uphill driving (too much load).
- No prolonged downhill driving (insufficient load and disadvantageous overrun condition).
- Do not use any engine braking systems.
- Do not drive on motorways or at top speed. Avoid driving on roads with frequent traffic jams.
- Overland rides and free-flowing city traffic are suitable. But avoid city traffic at extremely high ambient temperatures and during rush hours entailing many stops and waiting times at traffic lights.

⚠ **Attention**

There are running-in instructions for brand-new vehicles which are also applicable to reconditioned engines. If there is no test rig to carry out a defined running-in programme, it is obvious that the engine must be run-in on the road.

Regular oil-level checks during the running-in phase

Oil consumption may increase during the running-in phase. It is recommended that the oil level be checked after 50 to 100 km and the oil topped up if necessary. If the level on the oil dipstick has dropped considerably check the oil level at even shorter intervals. Do not overfill.

Oil change after 1,000 km

Although on modern engines in brand-new vehicles an oil change after the first 500 to 1000 km has not been necessary for quite some time, this is nonetheless recommended with reconditioned engines. The reason is that - frequently - not all wearing parts have been replaced or reconditioned. Due to previous engine failure, quite a lot of dirt remains circulating in the engine oil system or grinding dust and abraded metal due as a result of refinishing various components or from the running-in process are still there, and must be removed from the engine oil system after the running-in process by changing the oil and, most IMPORTANT! – replacing the oil filter.

⚠ **Attention**

Idling for hours is really harmful to the engine. An engine will not get run-in when it idles. Far from it. It might even be damaged. When the engine is idling, bearings and pistons are not adequately supplied with oil. Lubrication is impaired because the oil pump does not deliver much oil at idling speed. The oil flow through the bearings is minimised - and this at a conceivably bad time. Just when the adaptation processes the components are subjected to, are developing even greater heat due to frictional heat, there is not enough oil for lubrication and cooling.

Oil supply channels and lines may not be correctly vented and rinsed due to a lack of oil. Metal abrasion particles, dirt residues from reconditioning or previous damage which are still in the oil supply system cannot be rinsed off the engine bearings and washed off the cylinder wall quickly enough. It remains at the run-in spot where it immediately causes new wear.

And not to forget the fuel system. Especially on diesel engines with new or reconditioned injectors it is important that they are thoroughly rinsed. But the fuel quantities injected during idling are only minimal. As a result, a somewhat sluggish jet needle might not open or may not sufficiently atomise the fuel.

2.6.1

Out of true piston

Deformed or twisted connecting rods are often the result of engine failure. Whenever the small and large connecting rod eyes have not been checked for parallelism or if the connecting rod has not been aligned, the piston will not run straight in the cylinder bore (Fig. 1) during future engine operation. The piston rings can no longer rotate properly in the cylinder bore, but will adopt an elliptical shape, as shown in Figure 2. This results in serious sealing problems. The piston rings bear on one side on the lower edge, and on the other on the upper edge. Provided the ring is still capable of turning in the ring groove, it will adopt a convex shape within a very short time. This convexity far exceeds any convexity intended by the design making the lubricating film considerably thicker and efficient oil scraping impossible. In addition, the out of true piston causes a pumping effect on the rings and an increased oil inlet into the combustion chamber.

As a result of skewing, the piston rings are often no longer able to rotate and give way to ellipsis. This causes irregular radial wear which often leads to piston ring fracture.

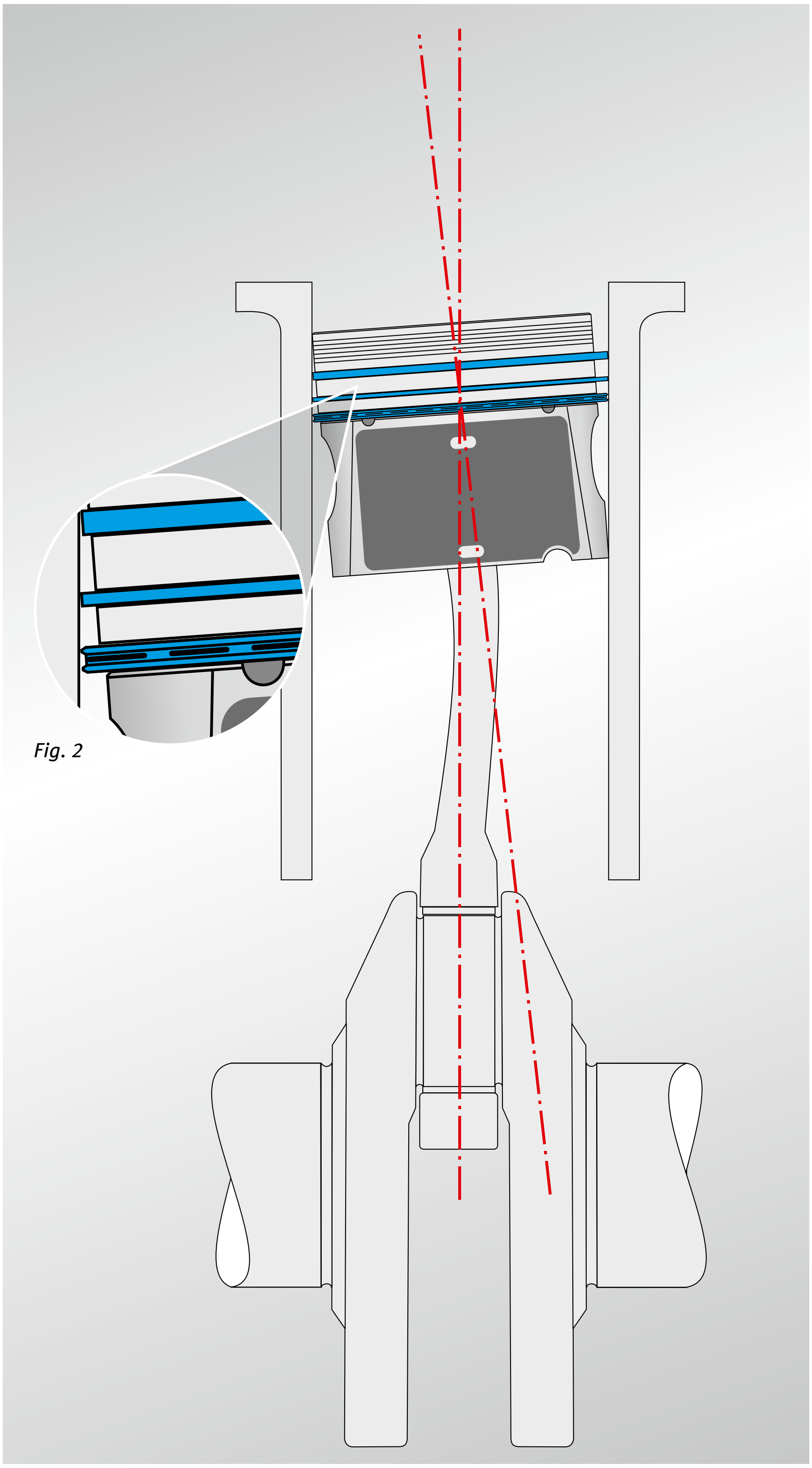


Fig. 2

Fig. 1

2.6.2

Oval bore

In cylinders with oval bores, the lower piston-ring tension means that the rings do not adapt to the cylinder wall at all, or they do so only very slowly, with the result that they are unable to provide their prescribed sealing function.

2.6.3

Ring sticking and rotation obstacles

Sealing problems frequently arise if the rings on four-stroke engines cannot rotate freely in the ring grooves. Damage to pistons and cylinder bores are then inevitable (overheating and piston seizure). Because of their shape, keystone rings (see chapter 1.3.1 Compression rings) are less susceptible to getting stuck or jammed inside the ring grooves.

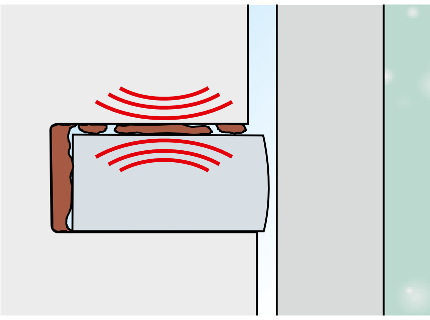


Fig. 1

Causes of ring blocking and how to prevent them

- The rings must not get axially jammed in the groove. The flatness of piston rings must be ensured. It is in any event essential to prevent piston rings from bending as a result of being incorrectly fitted onto the piston. (See chapter 2.4.1 Fitting and removing piston rings).
- The ring groove must match the size of the piston ring.
- The ring grooves must be free of dirt and other deposits.
- The engine oil must have the specifications required by the engine manufacturer. Using the wrong oil promotes carbon-fouling and jamming of the rings in their grooves.
- Operating the engine using vegetable oils and alternative fuels can also cause ring blocking.
- Using deformed connecting rods can cause the piston to skew in the cylinder bore.

2.6.4

Dirt

The intake of dirt into the engine is one of the most frequent reasons for premature wear to the engine and, consequently, also to the piston rings. Damage as a result of dirt has two main causes:

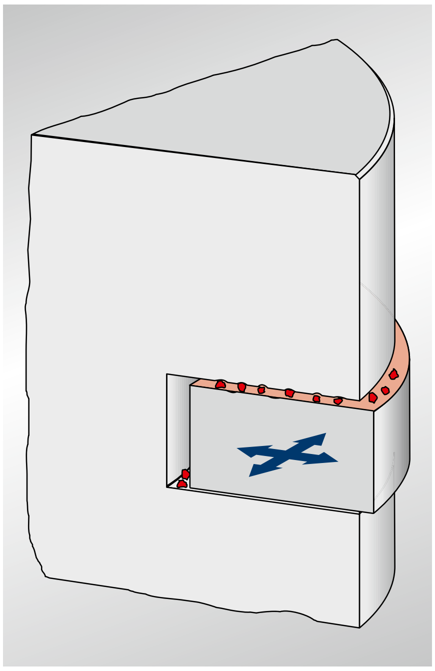


Fig. 2

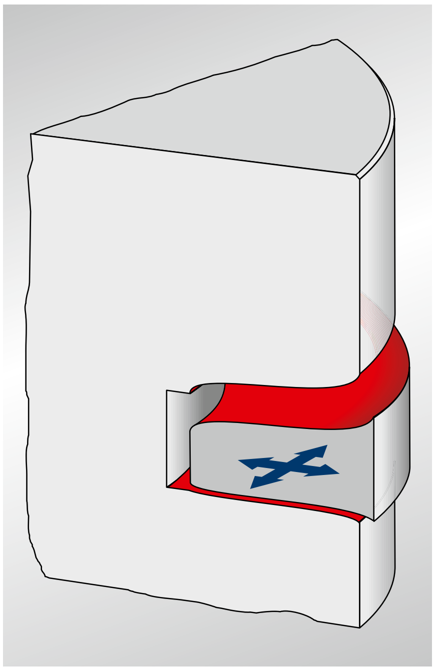


Fig. 3

Cause 1
Dirt reaches the combustion chamber together with the intake air. This always happens wherever the air filter servicing has been neglected. If the vehicle is driven without air filter or the intake system is leaky, the dirt can reach the combustion chamber without passing the air filter. The dirt in the combustion chamber will then also reach the piston ring grooves where it unites with the oil, forming an abrasive paste (Fig. 2). This reduces the height of the piston rings by grinding and enlarges the piston ring grooves (Fig. 3). The wear caused by dirt on the piston rings mainly occurs in the axial direction on the ring flanks. The ring will also wear in the radial direction (on the sliding surface) due to the resulting mixed friction, though not to the extent as on its flank. Roller marks on the ring flanks often indicate dirt in the ring grooves. The dirt, usually consisting of fine-grained sand, scratches characteristic patterns into the ring flank due to the rotation of the rings and the rocking movement of the piston. Since the rings abut mainly on the lower groove side during operation, the wear occurs mainly on the upper ring flank where the roller marks can be found Fig. 3 and 4 (page 62).

⚠ **Attention**
With a few exceptions, damage caused by dirt always affects all cylinder bores to an equal degree - usually cylinders that share one intake manifold or an air intake bridge. On adjacent cylinder bores supplied by one and the same intake manifold, it is practically impossible for damage due to dirt to only be caused on one cylinder bore. This is an important circumstance which must be considered when the diagnosing the damage. If only single cylinder bores are severely worn and provided a leak in the intake manifold for these cylinder bores can be excluded, the cause is presumable fuel flooding. (See Chapter 2.6.5 Fuel flooding).

Cause 2
The dirt is still in the oil circuit as a result of a previous damage and/or incorrectly conducted repair/reconditioning. Starting from the crankcase, the dirt then continues to wear out cylinder walls and pistons. Starting from the crankcase, the dirt then continues to deteriorate cylinder walls and pistons. Dirt particles can reach all bearing positions in the engine via dirty oil circuits. Although the oil is filtered in the oil filter, the oil circuit is frequently only inadequately cleaned. Dirt which has already reached the clean side of the oil circuit gets into the bearing positions, where it leads to premature wear or damage.

On damaged engines, the engine oil filter is often clogged by abrasive particles to such an extent that the bypass valve opens. Consequently, the engine oil reaches the lubricating points unfiltered. This circumstance is accepted by the engine design sector in order to prevent really serious engine failure caused by a complete loss of oil on the bearings. In many cases there is still lots of dirt in the oil radiator and its oil lines after an engine failure. It is therefore irresponsible to connect a new or reconditioned engine to an oil radiator which has not been cleaned and then start the engine. Because of bearing damage, such engines often do not even survive the test run.

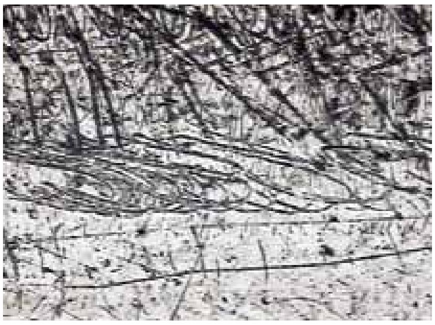


Fig. 1

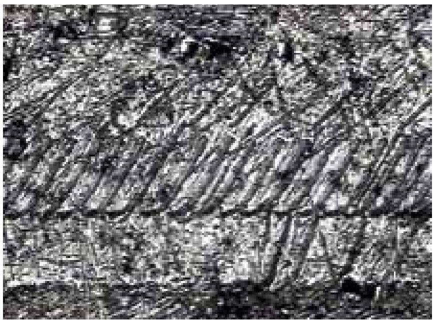


Fig. 2

Attention
If an oil radiator is clogged as a result of engine failure, cleaning only has little prospect of success. In such a case, it is better to use a new engine oil radiator to eliminate the risk which is inherent to using the used oil cooler.

2.6.5

Fuel flooding

The second most common cause of piston ring damage due to dirt is damage and wear as a result of fuel flooding. In the case of fuel flooding, the oil film on the cylinder wall is so severely affected that the piston rings rub off their metal on the cylinder wall and very quickly lose their radial wall thickness. Metallic contact between piston rings and cylinder wall (Fig. 4) should only occur briefly and in exceptional cases (e.g. during cold start) and is inadmissible during normal engine operation. The service life of pistons, piston rings and cylinder bore is considerably affected and drastically reduced. In their normal state, the interacting sliding parts are always metallically separated by an oil film (Fig. 3). In this process, the oil film must therefore be thicker than any unevenness on the surfaces of the interacting sliding parts.

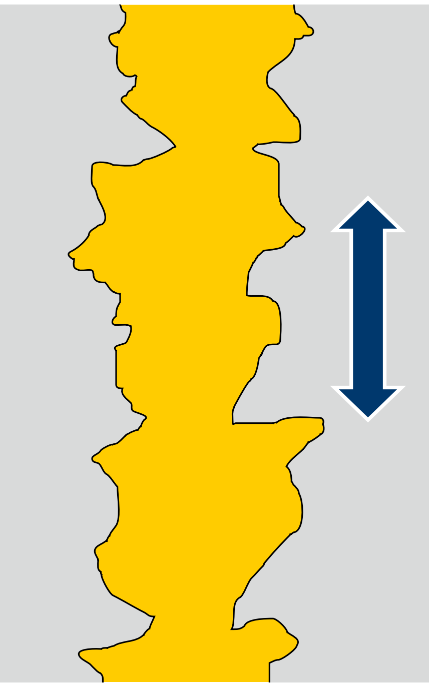


Fig. 3

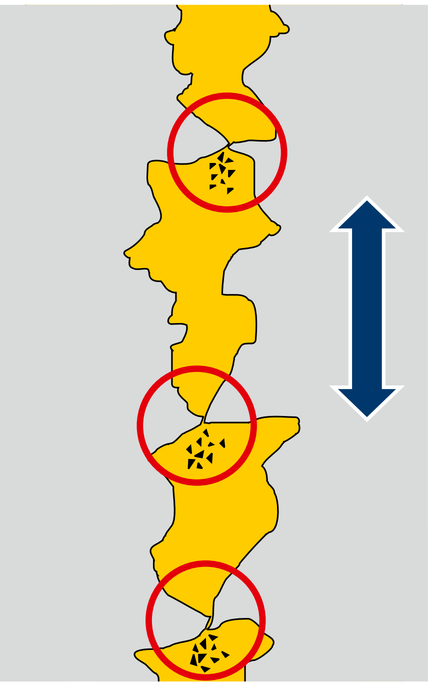


Fig. 4

During engine operation, abnormal combustion often leads to fuel accumulating and even condensing on the cylinder wall. The oil film is thus thinned or washed off. The resulting mixed friction causes the piston rings to wear out completely within a few thousands of miles. Performance drops and engine oil consumption increases.

Mixed friction leads to extremely severe radial wear to piston rings and cylinder surface which can easily be detected on the two scraping lands on the oil control ring. Figure 1, page 64 shows a new oil control ring and one which is worn due to mixed friction. Both scraping lands are completely eroded. The engine in which this ring was installed suffered excessive oil consumption. Such radial wear, which not only occurs on the oil control rings, can almost always be attributed to fuel flooding.

In particular whenever the wear is not evenly developed on all pistons, this can only be the result of mixed friction wear caused by fuel flooding. This occurs very often, proving that the rings are not worn out due to a presumed poor quality of material or defective cylinder machining. The latter would occur on all pistons and piston rings and not only on certain cylinders.

2.6 | Sealing problems and piston ring damage

Mixed friction wear due to fuel flooding occurs on petrol and diesel engines alike.

On petrol engines, this is mainly caused by short-distance rides (especially on older carburettor engines) and by misfiring. Petrol engines need much more fuel when starting and during the warm-up phase than at operating temperature. When short distances are frequently travelled, the condensed fuel adhering to the cylinder wall may possibly take longer to vaporise and instead unites with the engine oil. This causes oil dilution and, due to the loss of viscosity in the engine oil, results in mixed friction. On petrol engines, faulty spark plugs or ignition coils may cause fuel flooding since the fuel does not ignite and is not burnt.

On diesel engines, the injected fuel quantity ignites with the highly compressed air in the combustion chamber. Any lack of compression (incorrect filling) or inferior fuel quality results in ignition delay, incomplete combustion and the accumulation of liquid fuel in the combustion chamber.

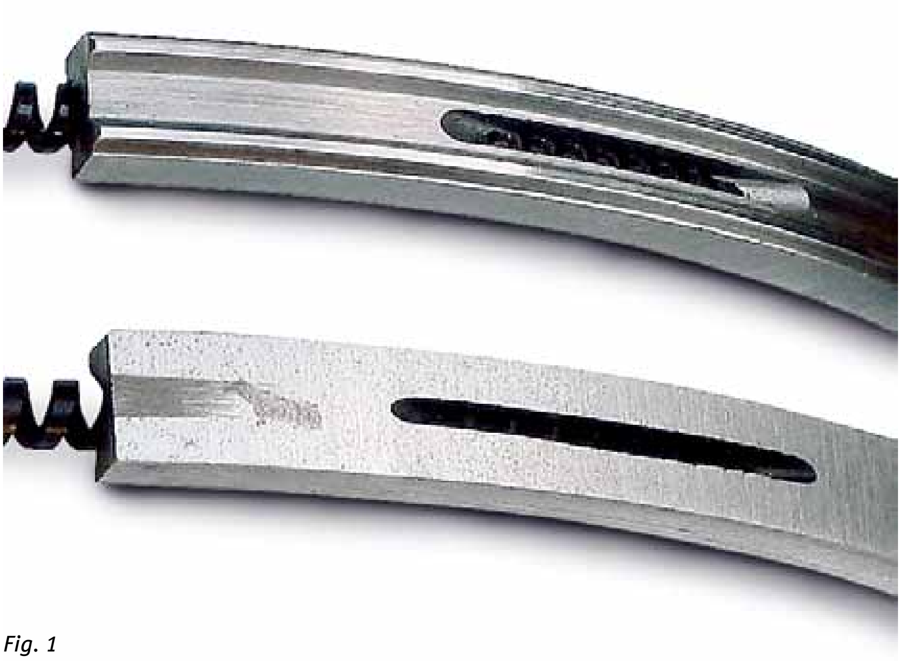


Fig. 1

Further reasons for fuel flooding on diesel engines are:

- Defective and leaking injectors.
- Faults on fuel injection pump and its setting.
- Incorrectly laid and fastened injecting lines (vibrations).
- Mechanical faults (piston impact on cylinder head) due to incorrect piston protrusion, caused by refinishing work on sealing surfaces and the use of cylinder head gaskets with the wrong thickness.
- Poor filling due to clogged air filters.
- Poor filling due to defective or worn turbochargers.
- Poor filling due to worn or broken piston rings.
- Poor fuel quality (inadequate self-ignition and incomplete combustion).

⚠ **Attention**

Even with this kind of damage, it must be distinguished whether wear has occurred on certain or on all cylinders. If all cylinders are damaged, a general cause is more probable, such as poor fuel quality or incorrect filling. Damage to individual cylinders is more likely to have been caused by faulty injection nozzles, injection lines, spark plugs or high-voltage cables.

2.6.6

Fractures

Piston ring fractures are caused by excessive wear, ring flutter or by mistakes when fitting rings.

Fractures while the piston rings are in operation only occur as a result of extreme operating conditions. While the rings are being fitted onto the piston, the mechanical stress is considerably higher than during operations. When slipping the rings over the piston, they are subjected to bending stress which is far higher than when being mounted into the cylinder. A ring with structural or material faults would already break during fitment. Whenever broken piston rings are found in an engine directly following a piston repair, these have previously been damaged or broken as a result of improper piston installation or by incorrect fitting tools.

Rings may break during operation after an extended service life. This happens if the radial or axial wall thickness has already been considerably thinner due to wear. Usually, the ring starts to flutter due to the increased ring height clearance and can no longer withstand the stress affecting it. The ring then breaks into lots of small fragments.

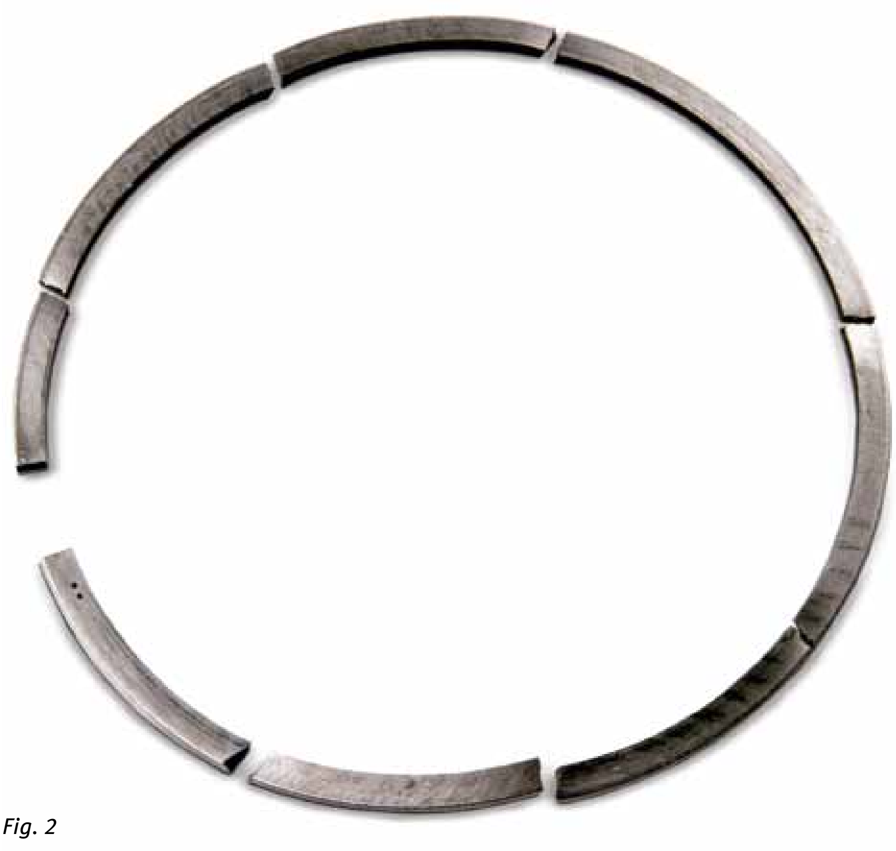


Fig. 2

However, rings do not need to have suffered from a reduction of the material thickness in order to break. If abnormal combustion occurs during operation, the rings may break due to high stresses, even if they are not worn. Ring fractures may also be caused by the unintentional entry of water or oil into the combustion chamber. Because liquids cannot be compressed. Whenever the amount of liquid exceeds the volume of the compression space, the liquid is pressed past the piston or the piston and/or piston rings will break). Likewise, it is possible that the connecting rod will bend or the cylinder wall/cylinder liner will break.

2.6.7

Ring flutter

Ring flutter can occur in particular on petrol engines at medium load and high engine speeds. Flutter refers to either a piston ring lifting off the lower flank contact area or a loss of the ring sealing effect as a result of a radial loss of contact with the cylinder wall (collapse).
Both will lead to power loss and high oil consumption, since the sealing function is altered or cancelled.

Axial ring flutter is mostly initiated from the joint ends into the ring. Due to their exposed position, the joint ends tend to lift off the lower contact area under unfavourable operating conditions. Vibration starts at the joint ends and are then transferred in waves to the entire piston ring.

Attention

Low ring heights have less tendency to flutter due to their lower inertia forces. The greater contact pressure on the joint ends counteracts the tendency to flutter.

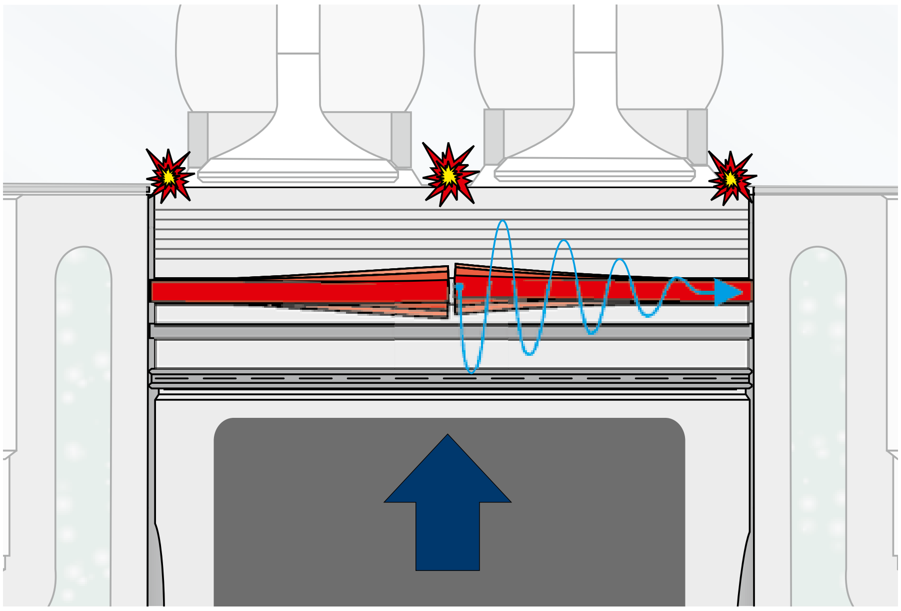


Fig. 1

Reasons for axial ring flutter:

- Excessive ring height clearance.
- Loss of ring tension (wear) and thus insufficient pressing performance on the joint ends, in particular on piston rings with pear-shaped radial pressure distribution (see also Chapter 1.6.2 Radial pressure distribution).
- Mechanical contact between piston and cylinder head due to reconditioning faults, in particular on diesel engines (Fig. 2).
- Knocking combustion as a result of faults in engine management (mixture formation, ignition) and due to poor fuel quality (too low octane rating, diesel admixtures).
- Worn piston ring grooves.
- Gas volume in groove base too low due to carbon deposits in the groove base. (Cause: too hot combustion temperatures and/or inadequate engine oil qualities).

Radial ring flutter

Due to disturbed interrelation of force (increase of gas pressure from the piston ring sliding surface), the piston ring may lift off the cylinder surface, resulting in loss of the sealing effect Fig. 2 and Fig. 1 (Page 68).

Causes:

- Worn piston rings (decrease of radial wall thickness) and consequent loss of pressure force of the piston ring against the cylinder wall and reduced ring stiffness.
- Out-of-round cylinder bores and associated increase of combustion pressure entering the sealing gap between piston ring sliding surface and ring gap.
- Out of true piston of piston due to deformed connecting rods. Due to its offset, the ring travels on a slightly oval course inside the cylinder bore. As a result, a greater quantity of combustion gas passes into the top land area and between piston ring and cylinder wall at the side of the cylinder where the piston has less contact.

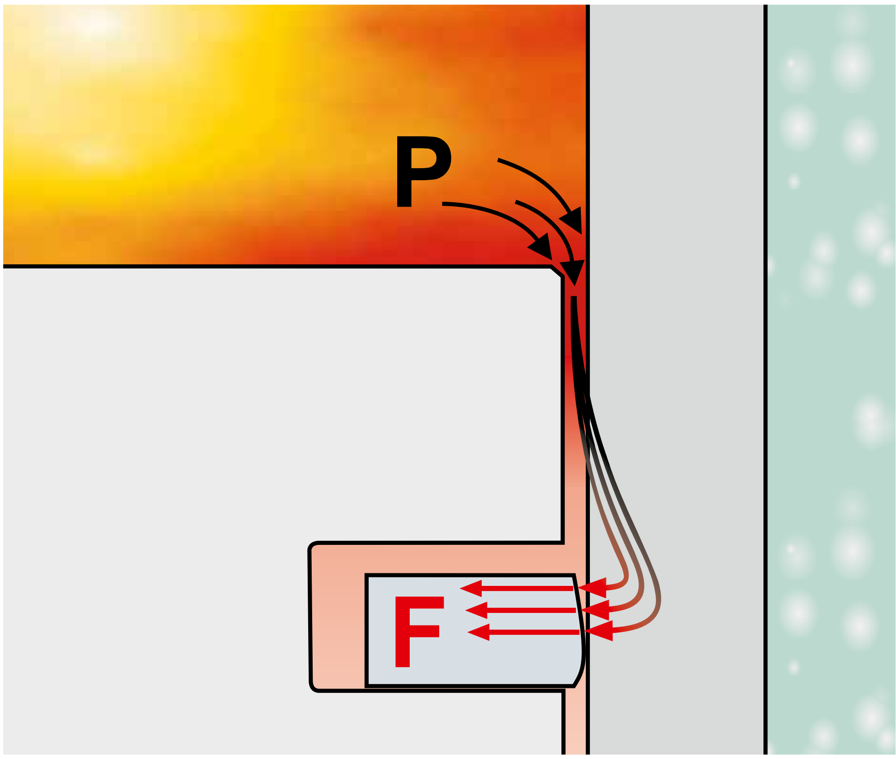


Fig. 2

2.6 | Sealing problems and piston ring damage

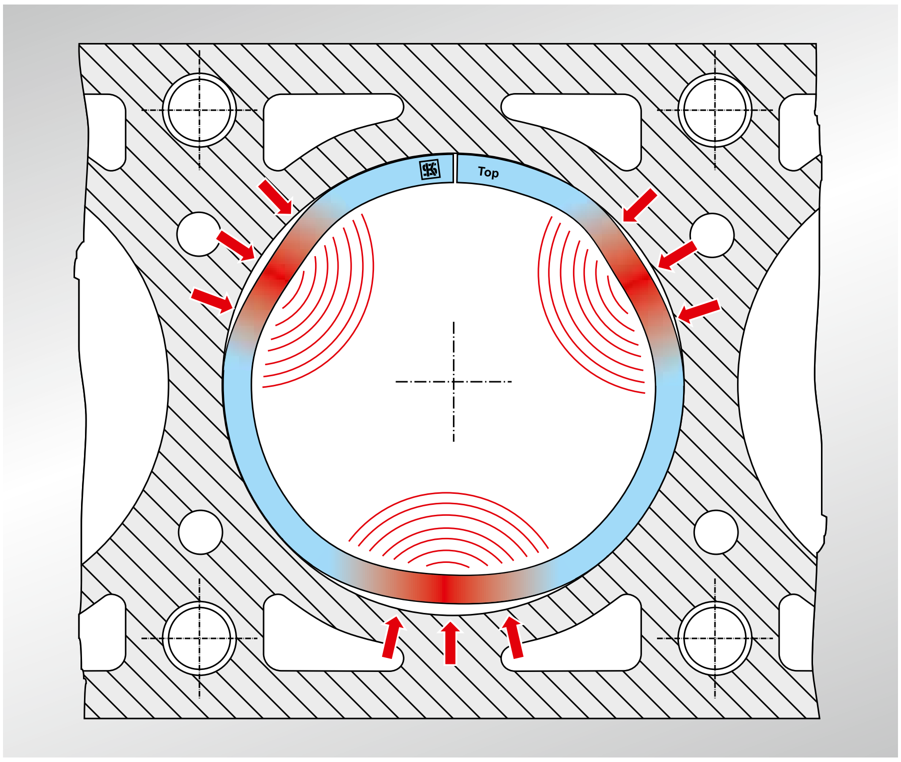


Fig. 1

- Excessive convex wear on the sliding surface of the piston ring as a result of too large ring height clearance.
- Damaged ring edges caused by improper honing (peak folding formation). The ring is torn and frayed on its edges (mainly on plain cast rings without surface coating), gas enters the sealing gap and lifts the piston ring off the sliding surface.

2.7.1

General

As a basic principle, the piston of a four-stroke engine is lubricated by splash and centrifugal oil from the crankshaft. The crank webs of the crankshaft do not normally immerse into the oil sump, since this would churn up the oil and also result in power losses. The oil required for lubricating the cylinder wall escapes from the bearing positions of the main and connecting rod bearings. Because the crankshaft rotates, this oil is distributed in droplets all over the crankcase and consequently also splashed on the cylinder wall whenever the piston is in the upper cylinder area.

On higher loaded engines or engines on which little oil escapes from the bearings, cylinder wall lubrication is ensured by using hollow-drilled connecting rods which splash additional oil on the cylinder wall on the thrust side of the piston (Fig. 2). Such measures are not necessary on engines provided with splash oil cooling for better heat dissipation. Direct oil cooling means that a sufficient quantity of oil runs back inside the piston, which then lubricates the cylinder wall.

Depending on engine speed, oil pressure and design characteristics, the droplet-formed oil quantities on the cylinder wall must be scraped off and distributed by the oil control rings. To achieve optimum lubricating effects with a minimum of oil consumption, the lubricating film on the cylinder wall should only have a thickness of 1-3 µm. A thinner lubricating film will cause mixed friction and high component wear, a thicker lubricating film will generally result in higher oil consumption. Causes of thick or thin oil film are also described in Chapter 1.5.6 Ball-shaped sliding surface shapes.

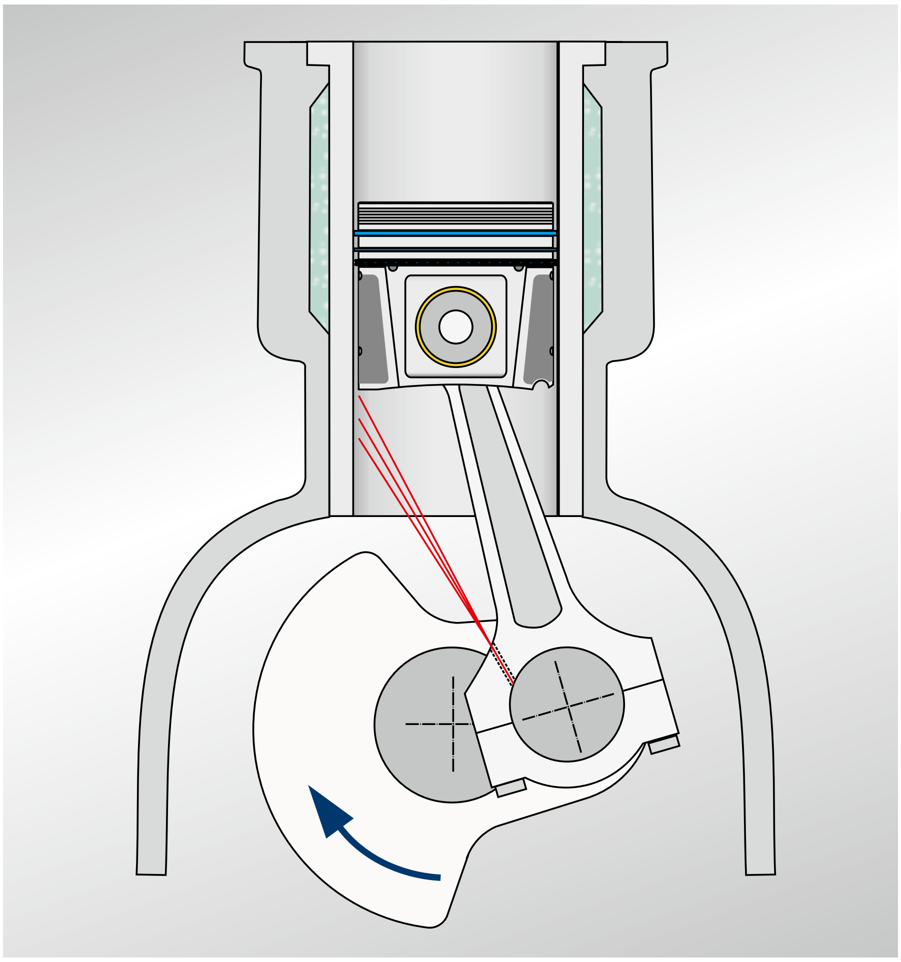


Fig. 2

2.7.2

Engine oil

Engine oil is the most important component in the engine. If the components were not lubricated and cooled by oil, it would be impossible to operate a combustion engine as we know and use it today. The oil separates the interacting sliding parts by a thin oil film and this lubrication prevents metallic friction and consequently, the wear between the interacting sliding parts. In addition, the engine oil is responsible for transporting heat and dirt within the engine.

Fig. 1

All essential tasks of engine oil at a glance:

- Lubrication (separation of metal surfaces moving against each other).
- Cooling (heat dissipation).
- Removal of dirt.
- Stability against shearing effect (caused e.g. by sharp piston ring edges).
- Sealing the combustion chamber towards the crankcase and inlet ports and exhaust gas channels via the valve guides towards the valve train.
- Dispersing solid external substances, dust, abrasion and combustion residues such as soot or ash.
- Protecting the engine components against corrosion caused by aggressive combustion residues by forming protective layers on the metal surface.
- Neutralising acid combustion residues by chemical transformation.
- Transmission of forces in hydraulic chain tensioners and valve tappets.
- Keeping the engine components clean by removing engine oil carbon deposits and ageing products using oil-soluble soaps.
- Wear protection (of engine components moving against each other).
- Rendering undesired combustion residues harmless.

Engine oil is composed of a base oil and additives, which are added to base oil to improve its characteristics. The content of additives and their composition are determined by the demands made on the oil.

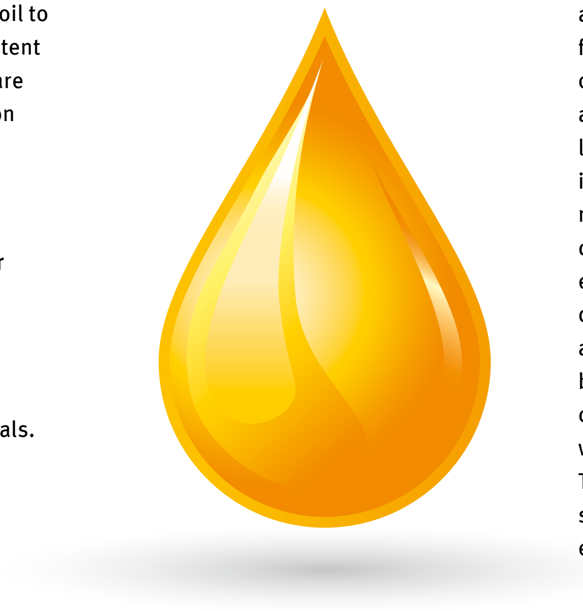
The additives act on or influence for instance the:

- Viscosity and flow properties.
- Surface-active performance.
- Neutralisation capability.
- Neutral reaction to sealing materials.
- Low tendency to foaming.
- Long service life, long oil change intervals.
- Low oil consumption.
- Low fuel consumption.
- Fuel compatibility.
- Environmental safety.

Engine oil is used up as a result of ageing and contamination. The additives in the oil are consumed and aggressive combustion residues and dirt foul the oil. Oil ageing is caused to some extent by high temperatures.

Engine oil is composed of long-chain hydrocarbon molecules. The viscosity of the oil is determined by the length of the molecular chains. Long molecules have a higher viscosity than short ones. Long molecular chains are chopped into smaller pieces by shearing effects during engine operation. This has an adverse effect on the viscosity and on the lubricating properties. In extreme situations, the oil is then less resistant and no longer capable of ensuring the desired lubricating properties.

It is useless to fine-filter the engine using special filtering measures outside the engine to remove the greatest possible amount of dirt particles. The oil itself has become the problem and not the dirt carried along with it.



Note: In some countries the oil is filtered through cloths and then resold.

In the course of the combustion process, acids and other harmful substances are formed which gradually decompose the oil. Heat is a major influence as it vaporises a portion of the oil components that boil at low temperatures, thus causing a change in the composition. The use of so-called microfilters that are said to make oil changes unnecessary throughout the entire service life of the oil is therefore questionable. Oil as well as expensive additives must be refilled in any case, because each engine has a natural oil consumption so that sooner or later there would not be any oil left in the engine. The installation of such supplementary systems would therefore not be very economical for the owner.

Summary:

Both base oil and additives are consumed in due course so that new oil (oil change) is necessary from time to time. By changing oil and filter, the harmful combustion residues are removed from the engine and made harmless. Fresh oil has better lubrication and cleaning properties and again offers reserves against all the harmful influences to which the oil is exposed.

2.7.3

Oil consumption in general

For experts, oil consumption is the quantity of oil which enters the combustion chamber and is burnt there. However, this does not include any oil which passes through the gaskets and drips off outside the engine. In such a case, this is called oil loss and not oil consumption.

Main causes of oil consumption:

- Defects on turbocharger (defective bearings, clogged oil return lines).
- Defects on mechanical fuel injection pumps (worn pump elements).
- Worn valve stem seals and valve guides.
- Faults in the sealing system piston-piston ring-cylinder bore (see next chapter).

Fig. 1

Important note:
Further information on the subject “oil consumption and oil loss” is available in the Motor Service brochure with the same title, which has also been published in the “Service Tips and Information” series.

2.7.4

Oil consumption due to piston-piston ring-cylinder bore

Oil consumption - normal or for design reasons
Oil reaching the combustion chamber from the crankcase passing piston-piston ring-cylinder bore is burnt and leads to oil consumption. Due to the design of the combustion engine and of the sealing system consisting of piston-piston ring-cylinder bore, there is always a certain “normal” oil consumption during engine operation.

The engine oil constitutes a thin oil film (approx. 1-3 µm thick) on the cylinder wall and, is exposed to hot combustion during the downstroke of the piston in the combustion cycle. Due to the hot combustion gases, small oil quantities are vaporised and burnt during every combustion cycle; after a while, this becomes noticeable as oil consumption. In addition, oil is ejected from the piston rings due to the reversal of the piston at the top dead centre and to the inertia forces produced. This oil quantity is burnt in the next combustion cycle.

Increased and excessive oil consumption
Excessive oil consumption caused by the piston-piston ring-cylinder bore sealing system is always attributable to causes for which the piston rings are not primarily responsible. Although the piston rings are involved, they are not the originators.

Reasons for excessive oil consumption caused by insufficient sealing effect of the piston rings:

- Worn rings (reduction of radial and axial wall thickness).
- Incorrect honing.
- Abrasive wear caused by dirt (Chapter 2.6.4 Dirt).
- Oval cylinder bores and/or out-of-round cylinder bores (see also Chapter 2.3.5 Cylinder geometry and roundness).
- Worn pistons (ring grooves) due to dirt and long running time.
- Worn cylinder bores (out-of-round, polished, distorted).
- Piston is out of true piston due to bent connecting rods (see Chapter 2.6.1 Out-of-plumb pistons).
- Incorrect oil specification.
- Used and overaged oil.
- Mixed friction as a result of flooding (see Chapter 2.6.5 Fuel flooding).
- Ring flutter (see Chapter 2.6.7 Ring flutter).
- Scratched sealing areas (groove lower flanks) due to improper cleaning of ring grooves.
- Rings stuck in their grooves due to dirt, carbon or deformed rings (improper handling).
- Absence of groove base clearance caused by wrong rings or carbon deposits (incorrect oil specification).
- Wrong ring assembly, incorrect ring heights, incorrect radial wall thickness, wrong shape (rectangular ring in keystone groove and vice versa).
- Faulty installation of oil control rings (incorrect installation of expander spring).
- Ring groove edges damaged by emery and cleaning measures.

2.7.5

Determining oil consumptions (comparative quantities)

Oil consumption can be quantified in various ways. In engine test runs on the test rig, oil consumption is specified in grammes per kilowatt hour. When testing, efficient sealing systems have oil consumptions ranging from 0.5 to 1 g/kWh. This kind of quantification cannot be applied in practice, as it is neither possible to determine the oil consumption exactly to the gramme nor to measure the performance in vehicle operations.

For this reason, oil consumption is frequently specified in litres/1000 km or as a percentage of the fuel consumption. The latter method has become accepted because it is much more precise than the specification in litres per 1000 km. This is due to the fact that engines are also in stationary use and vehicle engines have considerable idling times to some extent (traffic jams, waiting times at traffic lights, loading processes, and operating the air-conditioning). Added to these are the times during which the engine must be run to operate auxiliary units such as loading cranes or during pumping operations when the vehicle has not being driven any distance at all.

2.7.6

When is the oil consumption actually excessive?

Opinions on when the oil consumption is excessive vary greatly in practice and from one country to another. The widespread assumption or expectation that an engine does not or should not consume any oil at all is totally inaccurate, as explained above.

Every engine manufacturer has guide or limit values for the oil consumption of each of their engines. If excessive oil consumption is suspected, the respective engine manufacturer should be contacted to find out the guide or limit values for oil consumption. In many cases, workshop manuals and operating instructions also provide information regarding the oil consumption of an engine.

If no exact oil consumption data is supplied by the engine manufacturer, an oil consumption of between 0.25% and 0.5% in proportion to the actual fuel consumption must be calculated for trucks.

Example of calculation for trucks

A truck consumes about 40 litres of fuel per 100 km.
Projected this will equal about 400 litres of fuel for 1000 km.

0.25% of 400 litres fuel is equivalent to an oil consumption of 1 litre.
0.5% of 400 litres fuel is equivalent to an oil consumption of 2 litres.

Example of calculation for passenger cars

A passenger car consumes about 8 litres of fuel per 100 km.
For 1000 km, this means about 80 litres of fuel.

0.1% of 80 litres fuel is equivalent to an oil consumption of 0.08 litres.
0.5% of 80 litres fuel is equivalent to an oil consumption of 0.4 litres.

On smaller passenger car engines it may be a little less. In this case, the oil consumption will be between 0.1% and 0.5% of the fuel consumption.

Based on their functional principle, diesel engines consume more engine oil than petrol engines. Engines with a turbocharger also need more oil than engines without a turbocharger due to the turbocharger lubrication.

It is, however, clear that the oil consumption will be lowest after the running-in phase and that the consumption will increase in the course of the engine service life. Consequently, the minimum values should rather be regarded for new engines and the maximum values for engines which have already exceeded 2/3 of their service life. And with engines on which only partial repairs have been carried out (e.g. replacement of piston or even just piston rings), it cannot be expected that they will fall below the maximum value. All too often, the opposite is the case. All parts of an engine wear uniformly; and if only 10% of these parts are replaced, the improvement expected from a partial repair will also only be 10%.

2.7.7

Defining and dealing with oil consumption

As far as oil consumption is concerned, the following distinctions should be made:

Normal oil consumption 💧

This oil consumption is within the amounts specified by the manufacturer or within the values specified in the chapter above. There is no defect or reason for complaint.

Increased oil consumption 💧💧

The oil consumption for trucks would be twice or three times the normal oil consumption. With passenger car engines, approx. 0.5 to 1 litre/1000 km. The engine runs normally and does not necessarily show signs of blue smoke from the exhaust system.

Occurrence
On vehicles that have already exceeded 2/3 of their normal engine service life. Also on new, repaired and reconditioned engines which are still in their running-in phase. Engines that are operated under unfavourable conditions (hot ambient temperatures, frequent short-distance drives, idle mode, trailer operation, etc.).

Remedies
Not, or not necessarily, required, it is however essential to observe the oil consumption and to carry out oil level checks and top up the oil at regular intervals to ensure that the oil level is always at least at a minimum. If required, the reason for excessive oil consumption should be investigated. Besides the engine itself, accessories such as turbochargers, mechanical fuel injection pumps and vacuum pumps should be considered; or excessive oil consumption may be due to uniform distribution to all auxiliary components. It may be possible to improve the oil consumption by targeted repairs. If there is a fault on one of the accessories that has a significant affect on the oil consumption, this may also cause the oil consumption to increase suddenly. However, jumps such as this in the oil consumption are not to be expected if the components wear normally. Faults in the mixture formation/fuel injection, which become evident as black smoke in the exhaust system, also contribute considerably to piston and cylinder wear and, as a result, to excessive oil consumption. It is therefore essential to remedy such faults.

Excessive oil consumption 💧💧 💧💧

The oil consumption on passenger cars is more than 1.5 litres, on heavy trucks more than 5 litres.
Oil consumption not only becomes noticeable on the oil dipstick, but is also visible as blue smoke (in particular after overrun conditions). The amount of oil to be refilled entails considerable extra costs, justifying a thorough inspection, repair or reconditioning of the unit.

Occurrence
On completely worn engines and engine which have been incorrectly or inadequately reconditioned. In the case of engine failures, such as piston seizures, piston fractures, damage to turbochargers and cylinder heads or after a failure of other oil-lubricated accessories.

2.7.8

Checking and determining oil level and oil consumption properly

Oil level check

Reading errors frequently occur when checking the oil level, leading to misinterpretations of the actual oil consumption. The vehicle must be on a level surface; and after the engine has been cut off, the oil takes five minutes to return to the oil pan and drip completely. After pulling out the oil dipstick, hold it downwards to prevent the oil from flowing back along the stick and falsifying the measured value Otherwise, an incorrect oil level is detected and oil even topped up, although there is still sufficient oil in the engine. If there really is a lack of oil, fill it up slowly and in small quantities (about 0.1 litres at a time). Whenever oil is topped up too quickly or too much, the oil level will be too high. When the crankshaft immerses into the oil sump due to the excessively high oil level, the oil is churned up, stirred around and increasingly conveyed in droplets to the engine ventilation system. Since the engine ventilation system is connected to the intake air system, the oil is directed into the combustion chamber where it is burn.When refilling an engine after an oil change, the specified filling quantity should not be added, instead filling should be stopped, once the minimum level has been reached. The engine is started until the oil pressure has built up, then stopped, so that the oil has some minutes to return to the oil pan. Only then is the oil level measured and the oil quantity topped up to maximum.

Oil consumption measurement on the road

- Measure the oil level properly and top up to maximum.
- Drive the vehicle for 1000 km and note the fuel consumption for this distance.
- Check the oil level again after 1000 km and top up to maximum. The quantity that has been refilled is then the oil consumption for 1000 km.
- As an alternative (and this is a more accurate method), establish the ratio between the quantity of refilled oil and the documented fuel consumption and compare it with the values mentioned above.

Draining and measuring the oil prior to and after the measuring drive has not proven valuable in practice. Falsifications caused by oil loss, by drip pans and the like, are not compliant with an accurate measurement.

Oil filling quantities

The oil filling quantities specified in the manual or operating instructions must be regarded with extreme caution. Often no difference is made between the initial filling quantity (for the dry, oilless engine) and the quantity to be changed (with/without oil filter change).

The fact is that when the oil is changed, a certain amount of oil is left in the engine (in lines, channels, oil radiators, oil pump, power units as well as adhering to surfaces). If the initial filling quantity is then filled in when changing the oil, the level will be much too high. But the opposite can also occur. The quantity specified for changing oil may be too low. When the engine is started, oil will later be missing. If filling is incorrect and no further check is made, this is all too often interpreted as oil consumption. Care should also be taken that the viscosity of the oil is correct. Oil with low viscosity (thin) is consumed faster than oil with a higher viscosity. Only use oil that has been specified and approved by the engine manufacturer.

2.7.9

Complaints relating to oil consumption and their remedy

Complaints because of excessive oil consumption should in all fairness only be made if the vehicle has been properly serviced and the inspection intervals always observed. It is also essential that correct spare parts and the specified engine oil have been used. Excessive oil consumption does not occur suddenly. An engine will run without complaining, even with a higher oil consumption. Neglected maintenance and the resulting higher wear often only become evident when the vehicle is at an advanced age. Savings made in engine maintenance will be paid for in the end by way of excessive oil consumption and repairs that crop up sooner rather than later.

The success of repairs for eliminating excessive oil consumption depends to a large extent on the expenditure of time and material.

The vehicle owner or repair company consequently decides the quality of the repair result himself.

One thing is certain: Installing only new piston rings into a worn engine will allow it to continue running for a while; but it will not bring about any improvement in the oil consumption.

Fig. 1

Know-how Transfer

Direct access to our services ...

www.ms-motor-service.com

Training Programme

Specialist knowledge, direct from the manufacturer!
Every year, about 4,500 fitters and technicians benefit from our training sessions and seminars held on-site all over the world or at our training centre in Dormagen (Germany).

Technical Information

Information from professionals for professionals!
With our product information, service information, "Service – Tips & Infos" brochures, as well as posters and wall charts, you will always be right up to date.

News

First hand information!
Current issues, information, reports, new product launches and subscription to our newsletter.

Catalogues, CD, TecDoc

Fast and reliable!
With our comprehensive catalogues, on CD and in printed form, you can always find the right part for the right vehicle.

OnlineShop

Always up to the minute!
Even faster access to our latest product data, covering our full range.

Motor Service Partner:

Headquarters:
MS Motor Service International GmbH
Wilhelm-Maybach-Straße 14-18
74196 Neuenstadt, Germany
www.ms-motor-service.com

KOLBENSCHMIDT PIERBURG GROUP

4 028977 630637

© MS Motor Service International GmbH – 50 003 958-02 – 0110 EN

MOTOR SERVICE